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THE STUDENT'S LYELL

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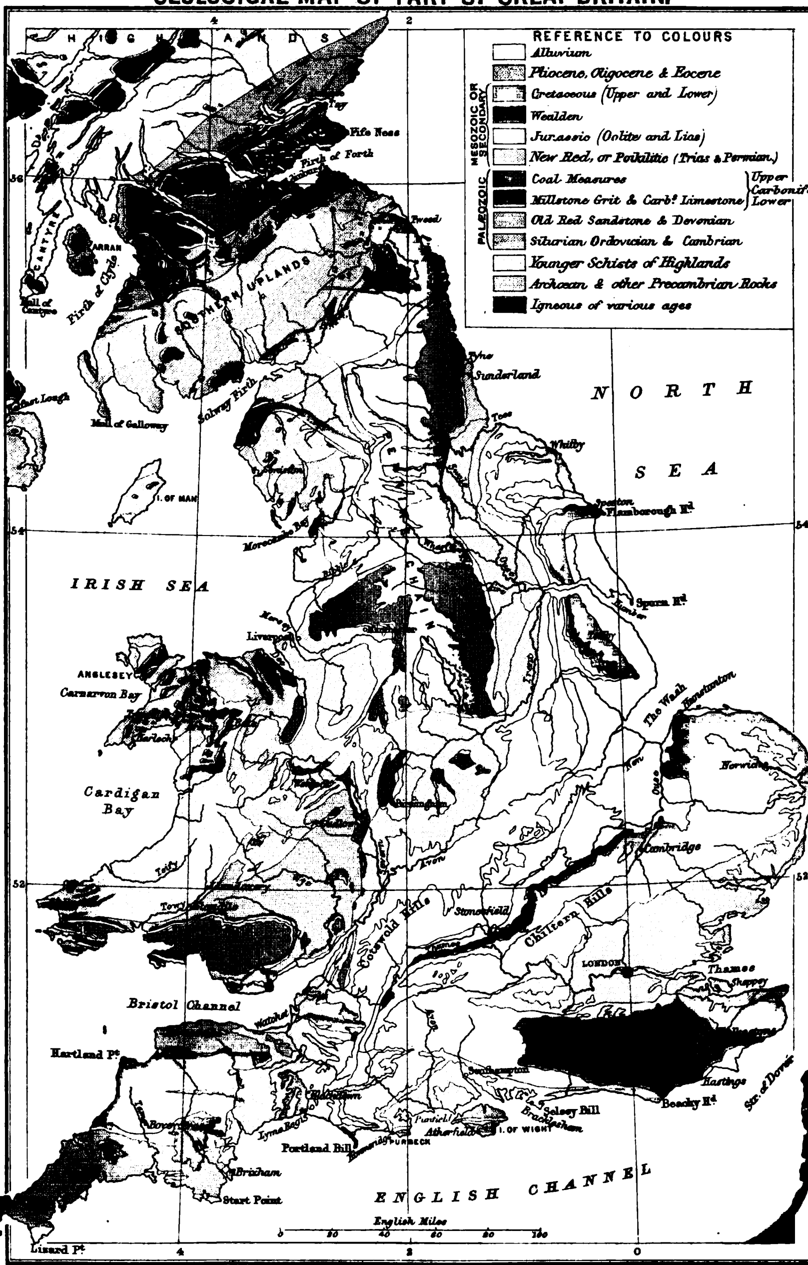
GEOLOGICAL MAP OF PART OF GREAT BRITAIN.



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THE STUDENT'S LYELL

A. MANUAL OF ELEMENTARY GEOLOGY

55637

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SIR CHARLES LYELL

WITH A GEOLOGICAL MAP
AND 736 ILLUSTRATIONS IN THE TEXT

LONDON
JOHN MURRAY, ALBEMARLE STREET
1896

PREFACE

THE writings of Sir Charles Lyell occupy so undisputed a position among the classics of science that neither explanation nor apology is needed for the issue of the present work. Its aim is to present—in a form suitable alike for students and general readers—an embodiment of those principles of geological teaching which will always be identified with the name of Lyell.

The 'Principles of Geology,' which appeared between the years 1830 and 1833, discussed the changes going on in the inorganic and organic world, as affording illustrations of the events which have taken place in past geological times; the 'Elements of Geology,' published in 1838, aimed, on the other hand, at explaining the whole sequence of geological phenomena in the light of observations made upon the existing course of nature. This latter book, of which the title was in 1851 changed to 'A Manual of Elementary Geology,' and which was in 1871 recast into a form more suitable for teaching purposes, under the name of 'The Student's Elements of Geology,' has formed the basis of the present volume; where, however, it seemed to be desirable, passages have been included from the other writings of the author.

When Sir Leonard Lyell offered to place in my hands for revision these writings of his uncle, I could not but feel gratified as well as honoured by the trust; for among my

most cherished recollections are those days of constant and friendly intercourse with Sir Charles Lyell during the period he was engaged in writing the 'Student's Elements' and in preparing the second edition. The progress of geological science, during the last quarter of a century, has rendered necessary very considerable additions and corrections, and the re-writing of large portions of the book, but I have everywhere striven to preserve the author's plan and to follow the methods which characterise the original work.

In spite of the expansion of the text and the introduction into it of more than one hundred new illustrations, it has nevertheless been found possible, by using smaller type for certain portions, to avoid increasing the bulk or the cost of the volume. It is hoped, moreover, that this employment of different kinds of type will afford some assistance to the student. The beginner is advised, in his first perusal of the work, to devote his attention mainly to the portions printed in larger type; and afterwards, in entering upon its more serious study, to read the whole through continuously. It may be well to mention, too, that although, for the very cogent reasons urged by Lyell (see p. 140), it is desirable in the first instance to study the newer and less altered strata before the older and greatly metamorphosed rocks, yet, in revising his studies at a later period, the reader may find it advantageous to take up the several systems in historical order.

Some of the additional illustrations to the book have been taken from the writings of Lyell's lifelong friend and fellow-worker Poulett Scrope; for others my thanks are due to the Trustees of the British Museum and to Dr. Henry Woodward, to Professor O. C. Marsh of Yale College, and to Dr. R. D. Roberts. The majority of the new illustrations have, however, been specially drawn for

the work by Mr. Gilbert Cullis, and to that gentleman and to Dr. W. Fraser Hume I am also indebted for much care in reading portions of the proof-sheets, while Professor T. Rupert Jones has supplied some valuable notes and corrections. Nor should I omit to mention that the work owes not a little to the labours of the late Dr. P. M. Duncan, who revised the fourth edition of the 'Student's Elements,' to the late Messrs. Searles V. Wood and David Forbes, as well as to Mr. Robert Etheridge and Professor T. G. Bonney, who aided Lyell in the preparation of the work for a second edition.

The size of the book of course precludes its being made an exhaustive treatise on geology, with full references to original memoirs; nor dare I anticipate that all my fellow-teachers will coincide with me in judgment as to what should be included in and what it is best to omit from a work with the scope and limits of the present one; yet I venture to hope that the modifications, rearrangements, and additions now introduced into the book have served to bring it up to date, and that teachers and students may alike find that it continues to be what Lyell made it—a convenient and trustworthy introduction to geological science.

JOHN W. JUDD.

KEW: *March* 1896.

As it is impossible to enable the reader to recognise minerals, rocks, and fossils by the aid of figures and verbal descriptions only, he will do well to refer to properly labelled specimens. Such may be seen in the British Museum of Natural History, the Jermyn Street Museum, and in many provincial museums. Specimens, rock sections, and microscopical preparations, &c., specially arranged to illustrate the different portions of this work, may be procured from Mr. F. H. Butler, 158 Brompton Road, London, S.W.

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Errata

Page 154, line 11 from bottom, *for* extent, *read* extinct
„ 193, in description of fig. 182, last line, *for* outlines, *read* outliers
„ 257, line 9, *for* Chalk, *read* Upper Chalk
„ 262, „ 3, *for* A lower, *read* The upper part of this
„ 277, „ 20, *for* Theoosimlia, *read* Theöosmilia
„ 277, „ bottom, *for* Gastriopoda, *read* Gastropoda
„ 318, „ 6, *dele* and jaws without teeth but
„ 326, „ 11, *for* Oxynotieras, *read* Oxynoticeras
„ 329, „ 1, *for* of, *read* or
„ 334, „ 6, *for* 450, *read* 451
„ 334, „ 26, col. 2, *for* Cretaceans, *read* Cretaceous
„ 376, „ 5, *for a.* Ventral valve. *b.* Inner side of dorsal valve, *read a.* Corallum. *b.* Operculum
„ 386, „ 5, *dele* Morte slates (without fossils). (Dr. Hicks has recently detected fossils in these beds which appear to show that the strata are of Silurian age faulted up in the midst of the Devonian.)
„ 423, „ 1, *for* Dicellocephalus, *read* Dikelocephalus
„ 536, „ 4 from bottom, *for* Tirkel, *read* Zirkel
„ 586, „ 28, *for* a Tertiary formation, *read* of Tertiary age

THE STUDENT'S LYELL

PART I

INTRODUCTORY

CHAPTER I

GEOLOGY DEFINED—HISTORY OF THE DEVELOPMENT OF GEOLOGICAL SCIENCE

Geology compared to History—Its relation to other Physical and Natural Sciences—Not to be confounded with Cosmogony—Opinions of Classical and Mediæval writers—Causes which have retarded the Progress of Geology.

Geology is the science which investigates the successive changes that have taken place in the inorganic and organic kingdoms of nature; it inquires into the causes of these changes, and the influence which they have exerted in modifying the surface and external structure of our planet.

By these researches into the state of the earth and its inhabitants at former periods we acquire a more perfect knowledge of its *present* condition, and more comprehensive views concerning the laws *now* governing its animate and inanimate productions. When we study history, we obtain a more profound insight into human nature, by instituting a comparison between the present and former states of society. We trace the long series of events which have gradually led to the actual posture of affairs, and, by connecting effects with their causes, we are enabled to classify and retain in the memory a multitude of complicated relations—the various peculiarities of national character, the different degrees of moral and intellectual refinement, and numerous other circumstances—which, without historical associations, would be uninteresting or imperfectly understood. As the present condition of nations is the result of

many antecedent changes—some extremely remote and others recent, some gradual, others sudden and violent—so the state of the natural world is the result of a long succession of events, and, if we would enlarge our experience of the present economy of nature, we must investigate the effects of her operations in former epochs.

We often discover with surprise, on looking back into the chronicles of nations, how the fortune of some battle has influenced the fate of millions of our contemporaries, when it has long been forgotten by the mass of the population. With this remote event we may find inseparably connected the geographical boundaries of a great State, the language now spoken by the inhabitants, their peculiar manners, laws, and religious opinions. But far more astonishing and unexpected are the connections brought to light when we carry back our researches into the history of nature. The form of a coast, the configuration of the interior of a country, the existence and extent of lakes, valleys, and mountains, can often be traced to the former prevalence of earthquakes and volcanoes in regions which have long been undisturbed. To these remote convulsions the present fertility of some districts, the sterile character of others, the elevation of land above the sea, the climate, and various peculiarities may be distinctly referred. On the other hand, many distinguishing features of the surface may often be ascribed to the operation at a remote era of slow and tranquil causes—to the gradual deposition of sediment in a lake or in the ocean, or to the prolific growth in the same of shells or corals. To select another example, we find in certain localities subterranean deposits of coal consisting of the remains of plants which have grown upon the spot, or have been drifted into seas and lakes. These seas and lakes have since been filled up, the rivers and currents which floated the vegetable matter can no longer be traced, the lands whereon the forests grew have disappeared or changed their form, and the species of plants that supplied the materials have for ages passed away from the surface of our planet. Yet the commercial prosperity and numerical strength of a nation may now be mainly dependent on the local distribution of fuel determined by that ancient state of things.

Geology is intimately related to almost all the physical sciences, as is history to the moral. An historian should, if possible, be at once profoundly acquainted with ethics, politics, jurisprudence, the military art, theology; in a word, with all branches of knowledge, whereby any insight into human affairs, or into the moral and intellectual nature of man, can be ob-

tained. It would be no less desirable that a geologist should be well versed in physics, chemistry, mineralogy, zoology, comparative anatomy, botany; in short, in every science relating to inorganic and organic nature. With these accomplishments the historian and geologist would rarely fail to draw correct and philosophical conclusions from the study of the various monuments of former occurrences. They would know to what combination of causes analogous effects were referable, and they would often be enabled to supply, by inference, information concerning many events unrecorded in the defective archives of former ages.

But the brief duration of human life and our limited powers are so far from permitting us to aspire to such extensive acquirements that excellence, even in one department, is within the reach of few; and those individuals most effectually promote the general progress who, after obtaining a general knowledge of the whole field of inquiry, concentrate their efforts upon some limited portion of it. As it is necessary that the historian and the cultivators of moral or political science should reciprocally aid each other, so the geologist and those who study physics or the biological sciences stand in equal need of mutual assistance. A comparative anatomist may derive some accession of knowledge from the bare inspection of the remains of an extinct quadruped, but the relic throws much greater light upon his own science when he is informed to what relative era it belonged, what plants and animals were its contemporaries, in what degree of latitude it once existed, and other historical details. A fossil shell may interest a conchologist, though he be ignorant of the locality whence it came; but it will be of more value when he learns with what other species it was associated, whether they were marine or freshwater, whether the strata containing them were at a certain elevation above the sea, and what relative position they held in regard to other groups of strata, with many other particulars determinable by an experienced geologist alone. On the other hand, the skill of the comparative anatomist and conchologist is often indispensable to those engaged in geological research, although it may rarely happen that the geologist will himself combine these different qualifications in his own person.

The analogy between the objects of research of the geologist and the historian extends no farther, however, than to one class of historical monuments—those which may be said to be *undesignedly* commemorative of former events. The buried coin fixes the date of the reign of some Roman emperor; the ancient encampment indicates the district once occupied by an

invading army, and the former method of constructing military defences; the Egyptian mummies throw light on the art of embalming, the rites of sepulture, or the average stature of the human race in ancient Egypt. The canoes and the hatchets, called celts, found in peat bogs and estuary deposits, afford an insight into the rude arts and manners of a prehistoric race, to whom the use of metals was unknown, while flint implements of a much ruder type point to a still earlier period, when man coexisted in Europe with many quadrupeds long since extinct. This class of memorials yields to no others in authenticity, but it constitutes a small part only of the resources on which the historian relies, whereas in geology it forms the only kind of evidence which is at our command. For this reason we must not expect to obtain a full and connected account of any series of events beyond the reach of history. But the testimony of geological monuments, if frequently imperfect, possesses at least the advantage of being free from either unconscious bias or intentional misrepresentation. We may make mistakes in our observations and the inferences which we draw from them, in the same way as we often misunderstand the nature and import of phenomena noticed in the daily course of nature; but our liability to go astray in geological inquiries is confined to errors of observation and to faults of interpretation; if observations and reasonings be alike correct, our conclusions are certain.

It was long before the distinct nature and legitimate objects of geology were fully recognised, and geology was at first confounded with many other branches of inquiry, just as the limits of history, poetry, and mythology were ill defined in the infancy of civilisation. Even in Werner's time, or at the close of the eighteenth century, Geology[1] appears to have been regarded as little other than a subordinate department of Mineralogy; and Desmarest included it under the head of Physical Geography. But the most common and serious source of confusion arose from the notion that it was the business of geology to discover the mode in which the earth originated, or, as some imagined, to study the effects of those cosmological causes through the action of which our planet passed from a nascent and chaotic state into a more perfect and habitable

[1] The word 'geology' did not come into general use till the commencement of the present century. Before that time the term 'geognosy' was employed for the branch of knowledge which we now designate as geology. For the subdivision of the science which deals with the general relations of rock-masses, without respect to their sequence in time, the old term geognosy may still be conveniently employed.

condition. The first who endeavoured to draw a clear line of demarcation between Cosmogony and Geology was Dr. James Hutton,[2] who declared that geology was in no way concerned 'with questions as to the origin of things.' But his doctrine on this head was vehemently opposed at first, and, though it has been continually gaining ground, it cannot even yet be said to be universally accepted.

History of the development of geological science.—In 1830 Lyell gave a sketch of the early history of geological thought and speculation, to show how mischievous had been the effects of confounding the objects of geology with those of cosmogony. He showed that the Indian, Egyptian, Grecian, and Roman philosophers —with some conspicuous exceptions—had altogether neglected the study of the monuments left to us of former changes in the earth's crust, to indulge in the more attractive but fruitless discussions concerning the origin of the world and the great catastrophes to which it was supposed to have been subjected. Certain Arabian writers of the tenth century, and afterwards the philosophers of Italy in the sixteenth, seventeenth, and eighteenth centuries—Leonardo da Vinci, Fracastoro, Steno, Scilla, Lazzaro Moro, Donati, &c.—with Hooke, Boyle, and Michell in England, Palissy and Buffon in France, and Raspi, Fuchsel, and others in Germany, laid the true foundation of a geological science, based on the observation of the existing order of nature. The growth of just geological ideas was hindered, however, by many prejudices. Fossils were long maintained to be, not the remains of organised beings, but strange 'freaks of nature,' the productions of a fancied 'plastic force.' When their organic nature was at last accepted, many gravely argued that fossils must be regarded, not as the remains of beings that had existed in the past, but as the prototypes of creatures that were to receive the endowment of life in the future! Even when all doubts had been removed concerning the true nature of fossils, it was only after considerable progress had been made in the study of the forms and structure of living beings that naturalists were able to realise the fact that many fossils represent forms of life which no longer exist upon the earth.

Still more detrimental to the progress of geology were the fixed prepossessions in the minds of nearly all men that the earth's existence had been limited to a few thousand years, and similar prejudices with regard to great catastrophes that were supposed to have happened in comparatively recent times.

Though these prepossessions are now to some extent removed, yet others still exist, from which it is not easy to free ourselves. Most of the relics of animal and vegetable life, preserved to us in a fossil state, have lived in the waters of the ocean, while our observations of existing nature are nearly all confined to the land surfaces on which we dwell. Many of the most important changes, occurring in the earth's crust, take place deep beneath the surface,

[2] Hutton's *Theory of the Earth* appeared in 1788, and in a more complete form in 1795. Dr. John Playfair's *Illustrations of the Huttonian Theory of the Earth* was published in 1802, and Lyell's *Principles of Geology* in 1830–33.

and concerning the nature and action of the operations going on there our experience on the earth's surface leads us to form only very inadequate conceptions. Last, and most important of all, perhaps, among the prejudices which have retarded the study of geological problems, we must regard those which are due to the effects produced on our minds by the magnificence of the phenomena themselves. It is very difficult at first sight to believe that the making of lofty mountains and deep valleys, the piling together of many thousands of feet of materials, and the passing away of whole generations of living creatures, have not been brought about by great and convulsive throes of nature rather than by simple causes operating through vast periods of time.

The student of geology, however, must be prepared, upon due cause being shown, to lay aside these prepossessions, and to guard his mind during all his inquiries against the influence of these prejudices. Two dangers, and two dangers alone, beset him—the chance of erroneous observation, and the risk of incorrect inference from observation. He who is not prepared to give up prepossession and prejudice, when just reasoning from careful observations demand the sacrifice, is unworthy to enter upon the study of science.

Since Lyell wrote the lines of this opening chapter, the advance of our physical and astronomical knowledge has enabled cosmogony to pass from the region of wild speculation, and to enter the circle of exact science. It has been maintained by some that the time has arrived when a judicious cosmology, which is the outcome of the application of correct physical principles to the explanation of cosmic phenomena, may be safely employed as the foundation of geology. But all experience shows that the dangers pointed out by Lyell as inherent to such a method still exist; and that just as it is wise of the historian to pursue his investigations into the events of the past, without any reference to the fascinating question of the origin of the human race, so the geologist is justified, when tracing back the story of the earth and its inhabitants, to avoid allowing any theoretical views concerning the beginnings of matter or life to influence his conclusions. Especially is it desirable for the student and beginner that this distinction between the objects of geology and cosmology should be kept in view.

There is one other point of resemblance between history and geology which it may be instructive to consider. The historian, when engaged in writing the annals of the more modern periods, is apt to be embarrassed by the abundance of the materials at his disposal. But as he passes backwards to the study of earlier times, this wealth of contemporary records—manuscripts, monuments, and inscriptions—gradually diminishes, till at last only a few inscribed stones, papyri, parchments, and coins are all he can rely upon in attempting to reconstruct the story of the earlier races of mankind. In the same way the geologist finds the most recent periods of the earth's history richly illustrated in deposits formed on the land as well as in the sea—materials accumulated by rivers, lakes, and glaciers—retaining all their characteristic features and structures, and replete with the relics of almost every class of animals and plants. But as he pursues his investigations farther back into the past, the evidence on which he has to rely becomes smaller and more fragmentary. Instead of the varied materials of later periods,

he finds only deposits that have been formed in the ocean, containing scarcely any remains of organisms besides those of marine animals, and these often very imperfectly preserved. Of still earlier periods the only records preserved consist of masses of rock, which have evidently undergone such an amount of chemical change that all traces of life, if they existed, must inevitably have been destroyed. The historical and the geological records alike commence in dimness and obscurity; and, interesting as the study of these beginnings of the two records must always be, it would be manifestly unwise to allow the imperfect ideas we are able to form of the events of these early times to unduly influence us in our conclusions concerning the later periods, of which we have such abundant and unmistakable evidence.

For further details concerning the History of Geology the reader is referred to the 'Principles of Geology,' Chapters II. to V.; to Fitton's 'Notes on the Progress of Geology in England' in 'Phil. Mag.,' 1832–33, and to the biographies of William Smith, Lyell, Darwin, Murchison, Sedgwick, Buckland, Owen, Edward Forbes, and Ramsay. Obituary notices with accounts of the work of other geologists will be found in the volumes of the 'Quarterly Journal' of the Geological Society in the Anniversary Addresses of the Presidents.

CHAPTER II

THE CRUST OF THE GLOBE

What geologists mean by the earth's crust—Physical characters of the crust of the globe—Chemical composition of the solid crust and of its liquid and gaseous envelopes—Distribution of temperature in the earth's crust—Distribution of pressure in the earth's crust.

OF what materials is the earth composed, and in what manner are these materials arranged? These are the first inquiries with which geology is occupied. We might have imagined at first sight that investigations of this kind would relate exclusively to the mineral kingdom, and to the various soils, rocks, and minerals, which occur upon the surface of the earth, or at various depths beneath it. But, in pursuing such researches, we soon find ourselves led on to consider the successive changes which have taken place in the former state of the earth's surface and interior, and the causes which have given rise to these changes; and, what is still more singular and unexpected, we eventually become engaged in researches into the history of the organic world, or of the various tribes of animals and plants which have, at different periods of the past, inhabited the globe.

All are aware that the solid parts of the earth consist of distinct substances, such as clay, chalk, sand, limestone, coal, slate,

granite, and the like; but it is commonly imagined that all these have remained from the first in the state in which we now see them—that they were created in their present form and in their present position. The geologist soon comes to a different conclusion, discovering proofs that the external parts of the earth were not all produced, in the beginning of things, in the state in which we now behold them, nor in an instant of time. On the contrary, he can show that they have acquired their actual configuration and condition gradually—under a great variety of circumstances, and at successive periods, during each of which distinct races of living beings have flourished on the land and in the waters, the remains of these creatures still lying buried in the crust of the earth.

By the 'earth's crust' is meant that small portion of the exterior of our planet which is accessible to human observation. It comprises not merely all the parts of the earth which are laid open in precipices, or in cliffs overhanging a river or the sea, or which the miner may reveal in artificial excavations; but the whole of that outer covering of the planet on which we are enabled to reason by observations made at or near the surface. These reasonings may extend to a depth of perhaps ten or fifteen miles; and this is a very small fractional part of the distance from the surface to the centre of the globe. But although the dimensions of such a crust are, in truth, insignificant in comparison with those of the entire globe, yet they are vast and of magnificent extent in relation to man and to the organic beings which people our globe. Referring to this standard of magnitude, the geologist may admire the ample limits of his domain, and admit at the same time that not only the exterior of the planet, but the entire earth, is but an atom in the midst of the countless worlds surveyed by the astronomer.

The materials of this crust are not thrown together confusedly; but distinct mineral aggregates, called rocks, are found to occupy definite spaces, and to exhibit a certain order of arrangement. The term *rock* is applied indifferently by geologists to all these substances, whether they be soft or stony, for clay, sand, and peat are included under this denomination. Our old writers endeavoured to avoid offering such violence to our language, by speaking of the component materials of the earth as consisting of rocks and *soils*. But there is often so insensible a passage from a soft and incoherent state to that of stone, that geologists of all countries have found it indispensable to have one technical term to include both, and in this sense we find *roche* applied in French, *rocca* in Italian, and *felsart* in German. The beginner, however, must constantly bear in mind that the

term 'rock' by no means invariably implies that a mineral mass is in an indurated or stony condition.[1]

Concerning the 'crust of the globe,' or that outer portion of the earth which is accessible to the geologist in his studies, it is desirable that we should bear in mind its general form, its density, chemical composition, and the distribution within it of temperature and pressure.[2]

Physical characters of the earth's crust.—The crust of the globe may be regarded as being made up of three portions, solid, liquid, and gaseous. The solid crust forms a complete envelope to the unknown interior, which may be solid, liquid, or even gaseous in parts. This part of the crust of the globe, which is built up of the solid materials we call rocks, is sometimes spoken of as the 'lithosphere.' The liquid materials of the earth's crust consist of water, with various salts held in solution in it; these masses of water occupy most of the depressions in the solid crust, but do not form a continuous envelope. They are sometimes spoken of as the 'hydrosphere.' The gaseous materials of the earth's crust consist of air, with some gases diffused through it, forming the 'atmosphere,' a continuous layer which envelops the solid and liquid portions of the crust, and has a depth of over 200 miles.

It must be borne in mind, however, that the limits between the solid, liquid, and gaseous portions of the earth's crust are by no means absolute and unchangeable. The waters not only flow over the surface of the solid crust, but penetrate it to great depths, and are returned to the surface in springs or sometimes, in volcanic districts, as vapour; portions of the water are also dissolved in the atmosphere, or are held in suspension by it as clouds. In the same way, the gases of the atmosphere are found dissolved in the waters of oceans, lakes, and rivers, and imprisoned in the rocks of the earth's solid crust. Lastly, the materials of the solid crust itself are found dissolved or suspended in a finely divided state in the waters, and even held up in suspension by the atmosphere.

In judging of the relations of the sea and land, the only standard we can employ is the level of the ocean. The highest mountains of the globe rise 29,000 feet above that level, and the deepest known oceanic depressions lie about the same distance below it. But the *average* height of the land is estimated as being only 2,200 feet, while the *average* depth of the ocean is no less than 12,600 feet. As, according to the most recent estimates, the land occupies only 28

[1] If all the materials of the earth's crust are designated as 'rocks,' it seems impossible to avoid calling by that name liquids, like mineral oils and the waters of springs, rivers, and the ocean. Even gases, like those emitted from volcanoes and locked up in the cavities of many solid rocks, must also be included under the same term. It is usual, however, to avoid departing so far from the popular use of the word, and to confine the term rock to the *solid* materials of the earth's crust, though this restriction is sometimes attended with considerable inconvenience.

[2] The study of the globe in its present condition, which is known as 'Erdkunde' by the Germans, is now generally designated in this country as 'physiography.' The study of physiography, or 'physical geography,' as some people prefer to call it, should, of course, precede that of geology, while the study of cosmogony should follow it.

per cent. of the whole surface of the globe, the volume of the ocean masses is about *fifteen times as great* as that of the land masses rising above the ocean level. This is a very important consideration which the geologist must take into account when he is studying the phenomena which result from changes in the relative positions of land and water on the globe.

While the earth, taken as a whole, has been shown to have a density or specific gravity of 5·5, the density of the solid crust is certainly much less than this. Most rocks have densities ranging from 2·6 to a little over 3. In a few rocks, like coal, peat, &c., the specific gravity is lower, and in some rocks, rich in compounds of the heavy metals, it is higher. Taking into account the relative abundance of rocks of different density, we may estimate the *average* density of all the rocks of the earth's solid crust at 2·75. This is exactly one half of the density of the whole globe. The density of the hydrosphere is less than two-fifths of that of the solid crust, and of the atmosphere at the earth's surface is $\frac{1}{1930}$ part of it, while at great elevations above the surface it is much less than this.

Chemical composition of the earth's crust.—The atmosphere is composed of the two gases, oxygen and nitrogen, mixed, but not combined with one another; the oxygen exists in some cases in its allotropic form of ozone, while the nitrogen is mixed to the extent of $\frac{1}{150}$ of its weight with the still more inert gas, argon; small but variable amounts of water vapour, carbon dioxide, and other gases are diffused through the atmosphere, while a few solid and liquid substances are held in suspension in it. The hydrosphere consists of water (a compound of hydrogen and oxygen) in which various soluble salts, gases, and suspended solids are present. The solid crust is much more complex in its composition, but is principally made up of various oxides, among which that of silicon plays the most prominent part, while the oxides of aluminium, calcium, magnesium, iron, potassium, sodium, and hydrogen, make up together by far the largest part of the remainder. From the general composition of rocks it has long been manifest that one half of the earth's solid crust consists of oxygen, one quarter of silicon, one-fourteenth of aluminium, while calcium, magnesium, and iron together make up one-tenth, sodium, potassium, and hydrogen together one-twentieth part of the whole.

Mr. F. W. Clarke, the chemist to the Geological Survey of the United States, has recently published a careful discussion of no less than 880 analyses of rocks with a view to determining the *average* composition of the earth's crust.[5] Assuming a thickness of solid crust of ten miles, he has arrived at the results given in the table on the opposite page.

The only other elements, besides those mentioned in the table, which are at all widely diffused in the earth's crust are fluorine, boron, nickel, zirconium, beryllium, the metals of the cerium group, and some of the heavy metals which are found to be present in very minute quantities in most rocks.

As all the elements form soluble compounds, they must be present in the waters of the ocean, though in very minute proportions. Thus gold and silver have both been detected in sea-water;

[5] 'The Relative Abundance of the Chemical Elements,' *Bull. U.S. Geol. Survey*, No. 78 (1891), pp. 34–42.

and it has even been estimated that the quantity of the former metal now distributed through the ocean must be many million times greater than that which has been extracted by man from the solid crust.

—	Solid crust 93 per cent.	Ocean 7 per cent.	Mean including air
Oxygen	47·29	85·79	49·98
Silicon	27·21	—	25·30
Aluminium	7·81	—	7·26
Iron	5·46	—	5·08
Calcium	3·77	·05	3·51
Magnesium	2·68	·14	2·50
Sodium	2·36	1·14	2·28
Potassium	2·40	·04	2·23
Hydrogen	·21	10·67	·94
Titanium	·33	—	·30
Carbon	·22	·002	·21
Chlorine	·01	2·07	·15
Bromine	—	·008	
Phosphorus	·10	—	·09
Manganese	·08	—	·07
Sulphur	·03 +	·09	·04 +
Barium	·03	—	·03
Nitrogen	—	—	·02
Chromium	·01		·01

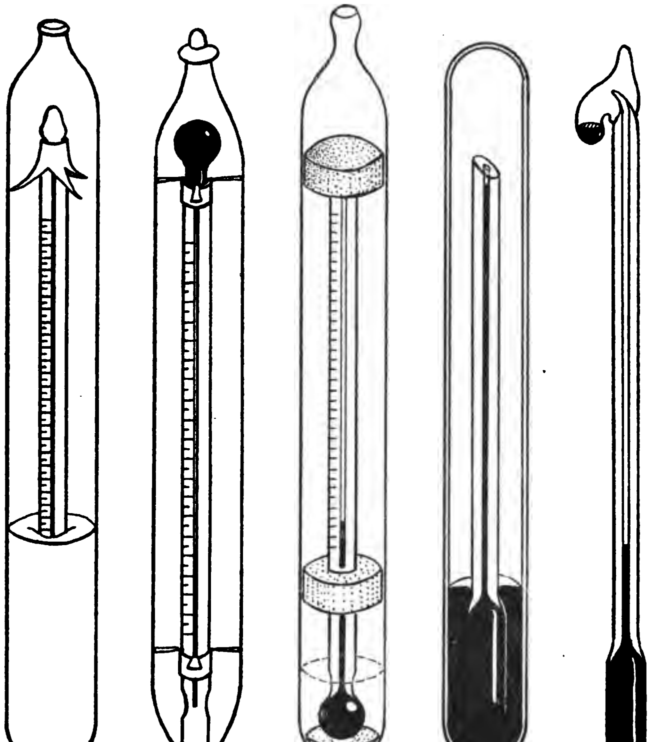
Distribution of temperature in the earth's crust.—In rising from the earth's surface into the highest points in the atmosphere which have been reached, we experience a constant and very rapid fall of temperature, but how far this progressive diminution in temperature continues is not known. In the same way, in descending through the waters of the ocean, a remarkable fall in temperature is found to take place, even in the warmest seas, till at a moderate depth water at only a little above 0°C. is found; and it is ice-cold water which occupies all the deeper parts of the oceanic depressions.

When we penetrate downwards into the solid crust of the globe, however, we everywhere experience a *rise* of temperature. At very moderate depths in all latitudes a stratum of invariable temperature is found, beneath which no changes due to daily or seasonal fluctuations are experienced. Beneath this stratum of invariable temperature we find (alike in tropical, temperate, and polar regions) a progressive rise in temperature in going downwards, and this is continued to the lowest points that have been reached.

The instruments employed in determining the temperature of the earth's crust are either slow-action thermometers, or some form of maximum thermometer. Slow-action thermometers are instruments surrounded with some badly conducting material, which prevents any appreciable change taking place in the indications of the instrument while it is being drawn to the surface. The forms of maximum thermometers which have been used for the determination of earth-

temperatures in this country are the inverted Negretti, and Phillips's thermometer improved by Sir William Thomson (Lord Kelvin). On the Continent, various forms of overflow thermometers are usually employed for this class of observation—the Magnus thermometer in Germany and the Walferdin thermometer in France (see fig. 1).

Fig. 1.



I. II. III. IV. V.

Thermometers employed in determining Earth-temperatures.

I. Slow-action thermometer, with its bulb surrounded with stearine.
II. The Inverted Negretti thermometer, with a constriction where the bulb joins the tube.
III. The Phillips thermometer with very narrow bore.
(The above instruments are employed in this country.)
IV. The Magnus overflow thermometer used in Germany.
V. The Walferdin overflow thermometer used in France.
(In the overflow thermometers it is necessary to raise the temperature after the instrument is brought to the surface, and when the mercury reaches the open end of the tube a reading is taken on a standard instrument placed beside it.)
All these instruments are protected from pressure by being enclosed in strong glass tubes, and from mechanical injury by being placed in metal cases. The figures are about half the size of the instruments themselves.

The observations by which earth-temperatures are determined fall into two classes: those made in mines, tunnels, &c., where access can be obtained by the observer to the spot where the temperature is to be taken, and those made in deep wells or boreholes (usually filled with water), into which the thermometer has to be let down by a cord or wire. In the first class of observations, a slow-action or maximum thermometer is allowed to remain for a considerable time in a hole bored in the solid rock, the mouth of the hole being closed with a tamping of fragments of the same rock. The chief sources of error in observations in mines and tunnels consist in the changes of temperature due to ventilation and other processes going on within them. In the case of deep wells and boreholes, the thermometer is let down and allowed to remain for a considerable time at the depth where it is desired to make a temperature observation. In such observations the principal risk of error is due to convection currents which must exist in all holes filled with water, but are least felt in boreholes of very small diameter. The action of such convection currents may, however, be neutralised by introducing water-tight plugs above and below the thermometer, and thus isolating the water in the part of the well or borehole where the observation is being made.

Although we everywhere find a more or less rapid rise in temperature in going downwards in the earth's crust, the *rate* of increase varies greatly in different localities. Many of the discrepancies can doubtless be accounted for by errors of observation, but when the fullest allowance is made for these the variations in different areas and even within the same area are often of a very startling character.

Professor Everett and the Committee on Underground Temperatures appointed by the British Association for the Advancement of Science have calculated that the *average* rate of the rise of temperature in going down into the earth's crust is 1°F. for every sixty feet of descent. Professor Prestwich has been led to regard many of the published observations as altogether untrustworthy, and his discussion of all the best observations leads him to the conclusion that the average rise of temperature is as rapid as 1° for 47·5 feet of descent, or even 1° for 45 feet of descent.

Another respect in which the results of underground temperature determinations show very marked discrepancies is in the uniformity or variation in the rate of increase in going downwards. In the case of the Sperenberg boring which was carried to a depth of 4,172 feet, there was exhibited a decided tendency to a diminution in the rate of rise in temperature in going downwards. In the Schladebach boring which reached a depth of 5,628 feet, the rate of increase (1°F. for 67 feet) was very uniform. In the case of the deep well at Wheeling (West Virginia), with a depth of 4,500 feet, the temperature increased from 1°F. for 82 feet in the upper part to 1°F. for 58 feet in the lowest portion.

The effects of variations in the specific heat and conductivity of rocks, and the influence of increased temperature and susceptibility to percolation of water, have all to be taken into account in considering the varied results given by observations on earth-temperatures.

Lines drawn through points in the earth's crust having the same temperature are called 'Isogeothermal lines' or 'Isogeotherms.' At present, the data for drawing such lines are very imperfect, but their distribution within the earth's crust is a matter of great

interest to geologists. There is reason to believe that beneath the ocean floors covered with ice-cold water, and in those parts of the continents enveloped in snow and ice, the isogeotherms are depressed and crowded together; while under the areas exposed to the atmosphere, and especially in mountain chains, the isogeotherms rise and become separated from one another.

Distribution of pressure in the earth's crust.—The effects of pressure on the density of different parts of the atmosphere are of the most marked character. When we rise to a height of 3½ miles, we have passed through one half of the atmosphere, and the tenuity of the higher portions of the gaseous envelope must be extreme. Water, though so comparatively incompressible, does yield to the weight of the column above in the deep oceans. Every thousand fathoms of descent is equivalent to an increase of pressure of one ton to the square inch. From the experiments which he made upon this subject, Professor Tait has concluded that the compression of the oceanic waters by the superincumbent mass leads, in the case of the deepest oceans, to a depression of the surface of the ocean of one furlong (880 feet), and that the average height of the ocean is 116 feet less than it would be if water were an absolutely incompressible substance.

Rocks, having a density 2·75 times greater than that of water, must produce a pressure of nearly three tons per square inch for every mile of descent. The effects of such pressures, not only in increasing the density of rocks, but in causing the penetration of ordinary liquids and gases (the latter often in a liquefied condition) through them, must be enormous. The minerals of nearly all the deeper-seated rocks, as we shall hereafter see, contain cavities filled with liquids, among which carbon-dioxide plays a very important part.

Fuller information concerning the physical characters of the earth's crust will be found by students in various treatises on physiography, such as that of Professor Huxley, and in Dr. H. Mill's 'The Realm of Nature.' Much valuable information on these questions is contained in the 'Reports of the Voyage of H.M.S. "Challenger."' The question of the chemical composition of the earth's crust is treated of at length in the 'Bull. U. S. Geol. Survey,' No. 78, and for a complete discussion of earth-temperatures the student is referred to Professor Everett's reports on Underground Temperatures in 'Rep. Brit. Assoc.' vols. from 1868 ownwards (see summary in vol. for 1886); also to Professor Prestwich's memoir on the subject ('Proc. Roy. Soc.' 1886), reprinted in 'Essays on Controverted Questions of Geology,' 1895.

CHAPTER III

ROCKS AND THEIR CLASSIFICATION

Classification of rocks according to their characters, origin, and age—Epigene rocks—Aqueous rocks—Volcanic rocks—Hypogene rocks—Plutonic rocks—Metamorphic rocks.

Rocks, or the solid materials of the earth's crust, may be classified according to several different principles. All rocks are built

up of *minerals*; but while the individual minerals making up a rock can sometimes be distinguished with the naked eye, or by the aid of a lens, it is, in most cases, necessary to prepare thin sections of rocks and to examine them with a microscope (often with very high powers) in order to discover the nature and peculiarities of the minerals which compose them.

Rocks which are built up of distinct crystals are said to be *crystalline*;[1] those made up of broken fragments are called *clastic*. A much more useful classification of rocks, however, is based on a consideration of their origin or of the conditions under which they have been formed. Nearly all the crystalline rocks, like granite and gneiss, are found to have originally underlain the rocks which have been formed at the surface, like sandstones, clays, and the different kinds of lava; while these latter do not as a rule occur underneath the highly crystalline rocks. The reason of this is, not that the crystalline rocks are necessarily older than the surface-formed rocks, but that they originated at considerable depths within the earth's crust. Hence we may distinguish all rocks as either *hypogene* or nether-formed rocks or *epigene* or surface-formed rocks. The epigene or surface-formed rocks include the *aqueous* rocks, formed by the action of water (of which class *aërial* or *Æolian* rocks, that is, materials accumulated by the action of wind, may be regarded as a subordinate group), and *volcanic* rocks produced by igneous agencies operating at or near the surface. The hypogene or nether-formed rocks include materials, like granite and diorite, which must have crystallised from a molten condition at great depths below the surface, and are called *plutonic* rocks, and rocks, which though originally aqueous or igneous in origin, have undergone great changes, and often complete recrystallisation of their materials, and are therefore called *metamorphic*, like gneiss and schist. We thus arrive at the following general tabulation of the rock masses of the globe:[2]

Epigene (or surface-formed rocks)	Aqueous (and Æolian). Volcanic.
Hypogene (or nether-formed rocks)	Plutonic. Metamorphic.

Epigene or surface-formed rocks.—The rocks of this class comprise materials the origin of which is obvious to us, living as we do upon the earth's surface.

[1] Vitreous, hyaline, or glassy rocks form a small class subordinate to the crystalline rocks.

[2] The terms 'hypogene' and 'metamorphic' were proposed by Lyell in 1833, in the first edition of the *Principles of Geology*.

Aqueous rocks.—The aqueous rocks, sometimes called also sedimentary or fossiliferous, cover a large part of the earth's surface, and they have evidently been formed under water. Some consist of mechanical deposits (pebbles, sand, and mud), and others are of organic origin, especially the limestones and coals. A few are of chemical origin, like rock-salt and gypsum. These rocks are usually *stratified,* or divided into distinct layers, or strata. The term *stratum* means simply a bed, or anything spread out or *strewn* over a given surface; and we infer that these strata have been generally spread out by the action of water, from what we daily see taking place near the mouths of rivers, or on the land during temporary inundations. For, whenever a running stream charged with mud or sand has its velocity checked—as when it enters a lake or sea, or overflows a plain—the sediment, previously held in suspension by the motion of the water, sinks by its own gravity to the bottom. In this manner layers of mud and sand are thrown down one upon another.

If we drain a lake which has been fed by a small stream, we frequently find a series of deposits at the bottom, disposed with considerable regularity, one above the other; the uppermost, perhaps, may be a stratum of peat, next below is a more dense and solid variety of the same material; still lower a bed of shell-marl, alternating with peat or sand, and then other beds of marl, divided by layers of clay. Now, if a second pit be sunk through the same continuous lacustrine *formation* at some distance from the first, nearly the same set of beds is met with, yet with slight variations; some, for example, of the layers of sand, clay, or marl, may be wanting, one or more of them having thinned out and given place to others, or sometimes one of the layers first examined is observed to increase in thickness to the exclusion of other beds.

The term '*formation*,' which has been used in the above explanation, expresses in geology any assemblage of rocks which have some character in common, whether of origin, age, or composition. Thus we speak of stratified and unstratified, freshwater and marine, aqueous and volcanic, ancient and modern formations.

In the estuaries of large rivers, such as the Ganges and the Mississippi, we may observe, at low water, phenomena analogous to those of the drained lakes above mentioned, but on a grander scale, and extending over areas several hundred miles in length and breadth. When the periodical inundations subside, the river hollows out a channel to the depth of many yards through horizontal beds of clay and sand, the edges of which are seen

exposed in perpendicular cliffs. These beds vary in their mineral composition, colour, and in the fineness or coarseness of their particles, and some of them are occasionally characterised by containing drift wood. At the junction of the river and the sea—especially in lagoons, nearly separated by sand-bars from the ocean—deposits are often formed in which brackish and salt-water shells are included.

In Egypt, where the Nile has added to its delta by filling up part of the Mediterranean with mud, the newly deposited sediment is *stratified*, the thin layer thrown down in one season differing slightly in colour from that of a previous year, and being separable from it, as has been observed in excavations at Cairo and other places.

When beds of sand, clay, and marl, containing shells and vegetable matter, are found arranged in a similar manner in the interior of the earth, we ascribe to them a similar origin; and the more we examine their characters in minute detail, the more exact do we find the resemblance. Thus, for example, at various heights and depths in the earth, and often far from seas, lakes, and rivers, we meet with layers of rounded pebbles, composed of flint, limestone, granite, or other rocks, resembling the shingles of a sea-beach, or the gravel in a torrent's bed. Such layers of pebbles frequently alternate with others formed of sand or fine sediment, just as we may see in the channel of a river descending from hills bordering a coast, where the current sweeps down at one season coarse sand and gravel, while at another, when the waters are low and less rapid, fine mud and sand alone are carried seaward.

If a stratified arrangement, and the rounded form of pebbles, are alone sufficient to lead us to the conclusion that certain rocks originated under water, this opinion is confirmed by the distinct and independent evidence of *fossils*, often very abundantly included in the earth's crust. By a *fossil* is meant any body, or the traces of the existence of an organic body—whether animal or vegetable—which has been buried in the earth by natural causes. Every stratum was the burial-ground of its time. Now the remains of animals, especially of aquatic species, are found almost everywhere embedded in stratified rocks, and sometimes, as in the case of many limestones, they are in such abundance as to constitute the entire mass of the rock itself. Shells and corals are the most frequent, and with them are often associated the bones and teeth of fish, fragments of wood, impressions of leaves, and other organic substances. Fossil shells, of forms such as now abound in the sea, are met with, far inland, both near the surface, and at great depths below it. They occur at

all heights above the level of the ocean, having been observed at elevations of more than 8,000 feet in the Pyrenees, 10,000 in the Alps, 13,000 in the Andes, and above 18,000 feet in the Himalaya.[5]

These shells belong mostly to marine forms of life, but in some places exclusively to forms characteristic of lakes and rivers. Hence it is concluded that some ancient strata were deposited at the bottom of the sea, and others in lakes and estuaries.

Aërial or Æolian rocks did not attract much attention in the early days of geology, but it is evident that they are forming at the present time over large surfaces of the earth, and that this was also the case in former ages. Changes take place on the surface of the earth which cannot be attributed to movements by water, and deposits accumulate which are also not referable to that agent. The vast deposits of loess in Eastern Asia have been attributed to blown dust; the desert sands of rainless regions, the sand dunes of many coasts and inland areas, and of the sides of lakes, are due to removal, by air in movement, of substances which have often been entirely eroded by atmospheric action and sometimes by water. Soils and thick deposits, like the laterite of Hindostan, are the result of chemical and other changes in the rocks exposed to the atmosphere. The accumulation of organic remains, both vegetable and animal in masses, often takes place without the intervention of an aqueous agency, and coal, peat, and some collections of bones, are examples of this action. Volcanic ash is wafted far and wide by wind, and gives rise to important deposits, many of which were formed on dry land. Frost breaks up rocks, and the débris may accumulate without being subjected to the action of moving water. Moraine matter, the product of land glaciers, and the blocks carried by ice, or simply remaining as the relics of subaërial denudation, must be regarded as belonging to this group of aërial rocks. Many of these rocks, however, assume the stratified form, and contain organic remains.

That aërial or Æolian rocks are not more commonly found among the stratified masses of the earth's crust is due to the circumstance that, before they can be covered up by marine deposits, such accumulations on the land must be subjected to the action of the waves and currents, and thus have their materials distributed to form ordinary aqueous masses.

Volcanic rocks.—The rocks which we may next consider are the volcanic, or those which have been produced at or near the surface, whether in ancient or modern times, by the action

[5] Gen Sir R. Strachey found Jurassic fossils at an altitude of 18,400 feet in the Himalaya.

of heat; such rocks are for the most part unstratified, and are devoid of fossils. Many volcanic rocks exhibit a parallel or banded structure, however; and we find lava streams alternating with beds of scoriæ and ash. These latter may sometimes be sorted while falling through air or water, and thus become stratified; when accumulated in seas and lakes, deposits formed in this way may occasionally include fossils. The volcanic masses are more partially distributed than aqueous formations, at least in respect to horizontal extension. Among those parts of Europe where they exhibit characters not to be mistaken, may be mentioned not only Sicily and the country round Naples, but Auvergne, Velay, and Vivarais, now the departments of Puy-de-Dôme, Haute-Loire, and Ardèche, towards the centre and south of France, in which are several hundred conical hills having the forms of modern volcanoes, with craters more or less perfect on many of their summits. Besides the parts of France above alluded to there are other countries, as the north of Spain, the south of Sicily, the Tuscan territory of Italy, the lower Rhenish provinces, Hungary, and many parts of Western America and Australia, where extinct volcanoes may be seen, still preserving, in many cases, a conical form, and having craters and often lava-streams connected with them. These cones are composed, moreover, of lava, scoriæ, and ashes, similar to those of active volcanoes. Streams of lava may sometimes be traced from the cones into the adjoining valleys, where they have choked up the ancient channels of rivers with solid rock, in the same manner as some modern flows of lava in Iceland have been known to do—the rivers either flowing beneath or cutting out a narrow passage on one side of the lava.

Although none of the volcanoes of Central France have been in activity within the period of human history, their forms are often very perfect. There are some volcanoes, however, which have been compared to skeletons, in which rain, streams, and torrents have washed their sides, and removed all the loose sand and scoriæ, leaving only the harder and more solid materials. By this erosion, their internal structure has occasionally been laid open to view, in fissures and ravines; and we then behold not only many successive sheets and masses of lava, sand, and porous scoriæ, but also perpendicular walls or *dikes*, as they are called, of volcanic rock, which have burst through and filled up the cracks in the other materials. Such dikes may also be observed in the structure of Vesuvius, Etna, and other active volcanoes.

There are also other rocks in almost every country in Europe, which we infer to be of igneous origin, although they do not

form hills with cones and craters. Thus, for example, we feel assured that the rock of Staffa, and that of the Giant's Causeway, called basalt, is volcanic, because it agrees in its structure and mineral composition with streams of lava which we know to have flowed from the craters of recent volcanoes. We find also similar basaltic and other igneous rocks associated with beds of *tuff* in various parts of the British Isles and also forming *dikes*, such as have been spoken of; and some of the strata through which they cut are occasionally altered at the point of contact, as if there had been an exposure to the intense heat of melted matter. The older writers were in the habit of calling the volcanic rocks of earlier geological periods by the name of 'trap rocks,' from the circumstance that the hills formed when such rock masses are denuded are apt to assume a terraced or step-like contour, from the Swedish *trappa* or stair. This term is now, however, seldom employed by geologists.

The absence of cones and craters, and of long narrow streams of superficial lava, in England and many other countries is to be attributed to the circumstance that, owing to the long period which has elapsed since their eruption, all the loose accumulations have been swept away by the action of rain and rivers. But this question must be enlarged upon more fully in the chapters on igneous rocks, in which it will also be shown that, as different sedimentary formations, containing each their characteristic fossils, have been deposited at successive periods, so also volcanic dust and scoriæ have been thrown out, and lavas have flowed over the land or bed of the sea, or have been injected into fissures, at many different epochs; so that the igneous as well as the aqueous and aërial rocks may be classed as a chronological series of monuments, throwing light on a succession of events in the history of the earth.

Hypogene or nether-formed rocks.—If we examine a large portion of a continent, especially if it contain within it a lofty mountain range, we rarely fail to discover two other classes of rocks, very distinct from either of those above alluded to, and which we can neither assimilate to deposits such as are now accumulated in lakes and seas nor to those generated by ordinary volcanic action. The members of both these classes of rocks agree in being highly crystalline and destitute of organic remains. The rocks of one class have been called plutonic, comprehending all the granites, diorites, gabbros, and certain 'porphyries,' which are allied in some of their characters to volcanic rocks. The members of the other class are more or less perfectly foliated or schistose in structure. They are the *gneisses and crystalline schists*, or metamorphic rocks in which

group are included gneiss, mica-schist, hornblende-schist, statuary marble, and other rocks afterwards to be described.

Plutonic rocks.—As it is admitted that nothing strictly analogous to these crystalline rocks can now be seen in the progress of formation on the earth's surface, it will naturally be asked on what data we can find a place for them in a system of classification founded on the origin of rocks. It may be stated, as the result of careful study, that the various kinds of rocks, such as granite, diorite, and gabbro, which constitute the plutonic family, are of igneous or aqueo-igneous origin, and have been formed under great pressure, at a considerable depth in the earth. The Germans speak of these rocks as *Tiefengesteine*, while the French geologists apply to them the name of 'roches de profondeur.' Like the lava of volcanoes, they have been melted, and have afterwards cooled and crystallised—but with extreme slowness, and under conditions very different from those producing the volcanic rocks. Hence they differ from the volcanic rocks, not only by their more crystalline texture, but also by the absence of tuffs and breccias, which are the products of eruptions at the earth's surface, or beneath seas of inconsiderable depth. They differ also by the absence of those pores or cavities, to which the expansion of the entangled gases and steam gives rise in ordinary lava.

Metamorphic rocks.—The last great division of rocks includes the foliated crystalline rocks and schists, called gneiss, mica-schist, chlorite-schist, talc-schist, quartzite, marble, and the like, the origin of which is more doubtful than that of the other classes. They rarely contain either pebbles, or sand, or scoriæ, or angular pieces of embedded stone, or traces of organic bodies, and they are often as crystalline in their structure as granite itself; they sometimes form bed-like masses, somewhat similar in form and arrangement to those of sedimentary formations. The bands or 'folia' of which they are made up consist of alternations of minerals varying in colour, composition, and thickness. According to the Huttonian theory, which is here adopted as the most probable, and which will be afterwards more fully explained, the materials of these rocks were originally deposited from water in the form of sediment, or thrown out from volcanoes as lava or dust, or consolidated beneath volcanoes as plutonic masses; but they have been subsequently so altered by heat, chemical action, and pressure, as to assume a new texture, and acquire a new mineral composition. It is demonstrable, in some cases at least, that such a complete conversion has actually taken place, fossiliferous strata having exchanged an earthy for a highly crystalline texture for the distance of a

quarter of a mile from their contact with granite. In some cases dark limestones, replete with shells and corals, have been turned into white statuary marble, and hard clays, containing vegetable or other remains, into rocks approaching in character to mica-schist, every vestige of the organic bodies having been obliterated.

In accordance with the hypothesis above alluded to, it was proposed in the first edition of the 'Principles of Geology' (1833) to employ the term 'Metamorphic' for the altered strata, the word being derived from μετά, meta, *trans*, and μορφή, morphe, *forma*.

From what has now been said, the reader will understand that each of the great classes of rocks may be studied from two distinct points of view. First, they may be regarded simply as mineral masses owing their origin to particular causes, and having a certain chemical composition, form, and position in the earth's crust, or exhibiting other characters, such as the presence or absence of organic remains. In the second place, the rocks of each class may be viewed as constituting a grand chronological series of monuments—attesting a long succession of events in the former history of the globe and of its living inhabitants.

We shall accordingly proceed to treat of each class of rocks; first, in reference to those characters which are not chronological, and then in particular relation to the several periods when they were formed.

If we desire to make a more special classification of rocks, it is necessary to determine the species of minerals of which they are built up, and the relations of these minerals to one another. Except in the case of some coarse-grained rocks, this can only be done by preparing thin transparent sections of the rock. Such transparent sections of rocks are produced by grinding down one side of a rock-fragment to a smooth and polished surface, cementing it upon a piece of glass, and then grinding away the exposed portion of the rock till nothing but a thin film remains. By the use of a lapidary's wheel and other apparatus, specially devised for the purpose, the work of making such rock-sections may be greatly facilitated.

The characters of the chief rock-forming minerals are described in Appendix A.

For works in which rocks are systematically described, the student is referred to Mr. Harker's 'Petrology for Students,' Mr. Rutley's 'Granites and Greenstones,' Dr. Hatch's 'Text Book of Petrology,' Mr. Teall's 'British Petrography,' and the Treatises on Petrography, published by Von Lasaulx, Zirkel, and Rosenbusch in Germany, and by Fouqué, Michel Lévy, and Lacroix in France.

PART II

AQUEOUS ROCKS

SECTION I. GENERAL RELATIONS OF THE STRATIFIED ROCKS

CHAPTER IV

COMPOSITION AND CLASSIFICATION OF AQUEOUS ROCKS

Chemical, mechanical, and organic deposits—Arenaceous rocks—Argilla ceous rocks—Calcareous rocks—Other varieties of aqueous rocks—Phosphatic deposits—Ironstones—Gypsum—Rock salt—Carbonaceous deposits—Peat—Coal—Anthracite.

IN pursuance of the arrangement explained in the last chapter, we shall begin by examining the aqueous (and aërial) or sedimentary rocks, which are for the most part distinctly stratified and often contain fossils. We may first study them with reference to their mineral composition, external appearance, position, mode of origin, organic contents, and the other characters which belong to them as sedimentary formations—independently of their age; and we may afterwards consider them *chronologically* or with reference to the successive geological periods in which they originated.

We have already given an outline of the data which led to the belief that the stratified and fossiliferous rocks were originally, with rare exceptions, deposited under water; but, before entering into more detailed investigations, it will be desirable to say something of the ordinary materials of which such strata are composed. They may be said to belong principally to three divisions—the arenaceous, the argillaceous, and the calcareous. Of these the arenaceous are chiefly made up of sand or siliceous grains; and the argillaceous of clays or compounds of silica, alumina, and water; while the calcareous rocks consist of calcium carbonate, with sometimes magnesium carbonate also.

Chemical, mechanical, and organic deposits.—A distinction has been made by geologists between deposits of a

mechanical and those of a chemical origin. Under the term mechanical deposits are designated beds of mud, sand, or pebbles, produced by the action of running water, as well as accumulations of lava, fragments, scoriæ, and dust thrown out of a volcano. These materials have been held in suspension in water or air, and have acquired their present disposition through the action of gravity. But the matter which forms a chemical deposit has not been mecha ically suspended in water but held in solution in the water till separated from it by chemical action. In this way calcium carbonate is sometimes precipitated in a solid form around springs, as may be well seen in many parts of Italy. In these springs the calcium carbonate is usually held in solution by an excess of carbon dioxide dissolved in the water; and, on the water escaping from the earth, the excess of gas passes off into the air, causing the dissolved calcareous matter to separate and be deposited on shells, fragments of wood, leaves, &c., encrusting and binding them together. The rock thus formed is called 'Travertine' (Tiber stone). Caves often have 'stalactites,' or pendent icicle-like masses, suspended from their roofs with layers on their floors ('stalagmite'), and these calcareous substances are in process of formation at the present time. Rain-water which has taken up carbon dioxide from the air, percolating through limestone rocks (in which caves are so often formed), takes up a certain amount of the calcium carbonate, and forms a soluble bicarbonate. The water thus charged drops from the roof, and gives off some carbon dioxide to the air, a corresponding amount of calcium carbonate being set free to form the pendent stalactites. The excess of water which drops on the floor of the cave, in some instances, gives off more carbon dioxide, and a further precipitation of calcium carbonate takes place to form the layers of stalagmite. There is, however, reason for believing, as shown by Professor Cöhn, that in nearly all cases in which travertine is formed an important part is played by vegetable organisms; these extract carbon dioxide from the water and thus facilitate the precipitation of the calcium carbonate.

No similar travertine ever appears to be formed upon the bed of the ocean, for, as a general rule, the quantity of calcium carbonate diffused through sea-water is so minute that direct chemical precipitation cannot take place. The separation of calcium carbonate from sea-water and the fresh water of many lakes and rivers appears to be due entirely to vital agency. Many plants and animals have the power of taking up from water the minute proportions of calcium carbonate, calcium phosphate, silica, &c., which it contains, and of building

these materials into their tissues. On the death of the organisms, the solid skeletons remain behind to form great rock-masses. In this way chalk and other forms of foraminiferal rock, various coral and shell-rocks, as well as bone-beds and certain siliceous deposits, are formed. Rocks thus produced by the action of vital agencies are known as *organic* deposits.

Arenaceous rocks (*psammites* of some authors).—These consist of masses of loose sand or of coarser materials which may become cemented together so as to form rocks of great hardness. We find many varieties dependent on the form and size of the constituent grains, the nature of the minerals forming the grains, and the substances by which the grains are bound together.

Most sands are composed of grains of quartz. These are sometimes perfectly angular, at other times subangular, and not unfrequently completely rounded into microscopical pebbles (*'millet-seed' sand*). There is reason to believe that all perfectly rounded sand-grains have at some period of their history been subjected to the action of the wind. The grains of sand found in deserts which have been acted upon by the wind are usually rounded and polished; and both Daubrée and J. A. Phillips have shown that but little rounding takes place in fine particles of quartz when suspended in water. We occasionally find sands made up of grains which have the external form of quartz crystals (crystalline sands and sandstones). It has been shown by Sorby and others that the original form of these sand-grains was irregular, and that their beautiful crystalline faces have been acquired by the deposition upon them of silica held in solution. In this way the fragments of old quartz crystals become enlarged and have their crystalline forms restored to them. By the aid of the microscope we can, indeed, see the old sand-grain lying in the midst of the crystal of quartz which has enveloped it. The sandstone of Penrith is a beautiful example of a crystalline sandstone. The red, brown, yellow, and other tints exhibited by sands are usually due to thin films of iron oxide more or less hydrated which have enveloped them. By the action of acids these surface films may be removed and a white or colourless sand left behind.

Sands mingled with water are known as *running* or *quick sands*; when moved about by the air they are called *blown sands* and form rounded hills (dunes). Dry sands sometimes give out a distinct note when struck or walked upon (*musical sands*). The sound produced by these musical sands appears to be due to a great number of particles of uniform size rubbing or striking against one another. *Desert* sands are

largely made up of well rounded and polished particles of quartz.

Sands are usually composed of particles of the mineral quartz or crystallised silica. Quartz is a very abundant and a very hard mineral, which has no tendency to split up into thin flakes, or, as the mineralogist says, it has no cleavage, and it is for these reasons that the great bulk of most sands is made up of quartz grains. Other minerals, however, often enter, sometimes very largely, into the composition of sands. Thus the fragments of quartz, felspar, and mica formed by the disintegration of a granite may accumulate to form a *granitic sand.* Such granitic sand when reconsolidated forms the rock known as *arkose.* Many sandstones contain a considerable proportion of particles of felspar, and these are known as *felspathic sandstones*, or *greywacké.* Other sandstones contain much mica, generally disposed along the planes of bedding, and are called *micaceous sandstone* and *flagstone.* Rarer minerals are found in sands and sandstones, by sifting out the minuter and heavier particles and separating these, according to their density, by dropping them into heavy liquids. Zircons, garnets, tourmalines, and many other minerals are thus shown to be often present in these rocks. By the study of sand and sandstones under the microscope, it is often possible to determine the nature of the rocks from which the loose materials have been derived by the action of denudation.

Sands differ much in the size of the grains of which they are made up. When the grains are very coarse many authors speak of the rock as a grit; but this name is given by other geologists to sandstones made up of angular grains. Rocks made up of loose fragments of all sizes, usually siliceous, are called *gravels*, and these are distinguished as *angular, subangular*, or *pebbly*, according to the degree of rounding of the fragments. Pebbly gravels, when consolidated into hard rocks, are known as *conglomerates* or pudding stones; angular fragments, when consolidated, form *breccias.* The siliceous particles of arenaceous rocks are sometimes bound together by calcareous matter (*calcareous sandstones* and *calcareous grits*); at other times iron oxide forms the cementing material, giving rise to what are known as *carstones.* Most usually, however, the cementing material in arenaceous rocks is silica, either partially or wholly crystallised. In such rocks the original boundaries of the constituent grains may sometimes be made out under the microscope, but are not unfrequently wholly lost. In this way the sandstone is found insensibly passing into the rock known as quartz-

rock or quartzite. The rocks known as *grey-wethers* or *sarsen-stones* are composed of sand cemented into a hard rock by silica deposited between the grains.

Various foreign admixtures may be found in sands and sandstones. When sand is largely mingled with argillaceous matter it is called a loam—but this term is more employed by agriculturists than by geologists. Sandstones may contain particles of silicates (glauconite &c.), usually of a green colour, which have been deposited in the interiors of organisms. These 'greensands' have sometimes been called 'chloritic sands' and 'glauconitic sands,' but neither name is very appropriate. The presence of other kinds of foreign materials gives rise to carbonaceous, ferruginous, or argillaceous sands and sandstones.

Argillaceous rocks (*pelites* of some authors) include all the varieties of mud, clay, and their hardened representatives, such as shale and clay-slate. These rocks are composed essentially of silicate of alumina, with varying quantities of water. The purest clay is *kaolin*, or porcelain clay, which contains 46 per cent. of silica, 40 per cent. of alumina, and 14 per cent. of water. In *Fuller's earth* the proportion of silica is higher and of alumina less, but the material contains 30 per cent. of water and considerable quantities of other substances (iron oxide, lime, and magnesia), which may be regarded as impurities. Most clays probably consist of these and other hydrated silicates of alumina mingled with minute fragments of many other minerals. On account of the minuteness of the mineral particles which compose them, it is often difficult, even with the highest powers of the microscope, to make out the mineralogical constitution of clays. Many of the hydrated silicates of alumina form crystalline scales like mica, and these can be detected by the microscope. By carefully washing clays in water, fine needles of rutile (oxide of titanium) and fragments of other minerals may be isolated. Most clays exhibit the important property of plasticity, which renders them so valuable for making bricks, tiles, and various kinds of pottery. One general character distinguishing the argillaceous rocks is that of giving out a peculiar earthy odour when they are breathed upon.

Pipe clays are white clays nearly free from the hydrated oxides of iron which communicate red, yellow, and brown colours to most argillaceous rocks. Many varieties of clay when dug at some depth from the surface have a dark-blue colour, which is due, as was shown by Ebelmen and Church, to the presence of finely divided iron disulphide (iron pyrites). *Fire-clays* or *refractory clays* contain a considerable amount of uncombined silica,

which makes them difficult to fuse; such clays are used for making crucibles and lining furnaces. Clays frequently contain large quantities of foreign matter, and are known as *carbonaceous*, *micaceous*, *sandy*, or *ferruginous* clays. Clays containing much calcareous matter are properly called *marls*; but this name is often incorrectly applied to true clays containing little or no calcium carbonate.

Hardened clays which are not fissile are often called *mudstones*. When induration is accompanied with the development of a laminated structure along the planes of bedding, the rock is called a *shale*. Some carbonaceous shales yield hydrocarbons when subjected to distillation, and these are known as *oil-shales*. *Torbanite* is a valuable oil-shale found in the carboniferous rocks in the south of Scotland. Near great igneous masses argillaceous rocks pass into a material of great hardness, density, and fineness of grain, which is called *flinty-slate*, *Lydian stone* (Lydite), and *porcellanite* or *argillite*. Some of the argillaceous rocks which have been altered by the contact of great igneous masses are found to be filled with microscopic crystals of garnets and other hard minerals. In consequence of the presence of these the rocks are employed for grinding and polishing purposes (*whetstones*, *novaculites*). In other cases, larger but ill-defined crystalline particles separate in such rocks, giving rise to what are known as *spotted slates*. When distinct minerals like chiastolite, ottrelite, &c., can be made out with the naked eye, the rocks are called chiastolite slate, ottrelite slate, &c.

Some argillaceous rocks split up along planes distinct from the planes of bedding. These rocks constitute slates or clay-slates. When minerals like mica, talc, chlorite, &c., are developed along the planes of separation or cleavage, the clay-slates pass into what are called phyllites, or, as they are often called by English writers, mica-slate, talc-slate, chlorite-slate, &c. These rocks constitute a transition between the classes of aqueous and metamorphic rocks.

Calcareous rocks (or **limestones**) consist of calcium carbonate often combined with more or less magnesium carbonate. They are usually of organic, but occasionally of chemical origin. When composed of calcium carbonate they effervesce freely when a drop of dilute acid is placed upon them. If the geologist finds it inconvenient to carry a bottle of liquid acid in the field, he may use solid substances like phosphoric, oxalic, and citric acids, adding a drop of water. When the quantity of magnesium carbonate in a rock is large, the effervescence with acid is decidedly less brisk; such rocks are called *magnesian*

limestones. When we have the definite compound of the magnesium and calcium carbonates known as *dolomite*, we get no effervescence at all with cold dilute acid. Even dolomites, however, effervesce and dissolve when the acid is warmed. When limestones are heated they give off the carbon dioxide, and anhydrous calcium oxide (quick-lime) is left behind. If water be added to the quick-lime a hydrated calcium oxide (slaked lime) is formed with great evolution of heat.

Travertine, with its varieties stalactites and stalagmite, have already been mentioned as examples of chemically formed limestones. Pisolite and oolite (roestone) are made up of rounded grains composed of concentric coats of calcium carbonate enveloping a fragment of shell or other foreign substance. Recent studies point to the conclusion that the formation of all these substances is not due to chemical action alone, but that various lowly vegetable organisms play an important part in removing the excess of carbon dioxide in the water, and causing the deposition of the calcium carbonate.

Most of the limestone rocks found in the earth's crust are undoubtedly of organic origin, and are built up of the remains of various plants (calcareous algæ), or of the skeletons of animals, such as foraminifera, corals, bryozoa, mollusca, &c.

Some organisms have their skeletons composed of calcium carbonate in the form of the mineral calcite, others in the form of the mineral aragonite, while some skeletons are made up of both these minerals. Aragonite is an unstable mineral, and calcite a stable one, but the former may be converted into the latter. Organic structures composed of aragonite are either dissolved away (leaving empty casts) or are converted into 'pseudomorphs' of calcite.

Chalk is a soft foraminiferal limestone. Other limestones made up of foraminifera are the *nummulitic limestones*, the *orbitoidal limestones*, the *fusulina limestones*, &c. *Entrochial limestones* are made up of the stems of crinoids; and various kinds of *shell limestones* consist of the remains of different species of mollusca; limestones made up of bryozoa (like the so-called '*coralline crag*') have also received distinctive names.

Oolite limestones are made up of small rounded grains, like the roe of a fish. When the grains are of larger size—approaching that of a pea—the rock is called a pisolite ('pea-grit'). Recent investigations tend to show that oolites and pisolites probably owe their formation to the action of minute aquatic plants (algæ). In thin sections, oolitic and pisolitic grains are seen to exhibit a remarkable concentric and radiated structure. Rocks made up

of oolitic grains are found of all ages, and similar rocks are being formed at the present day in the coral reefs of the Bahamas and in the Great Salt Lake of Utah.

Fig. 2.

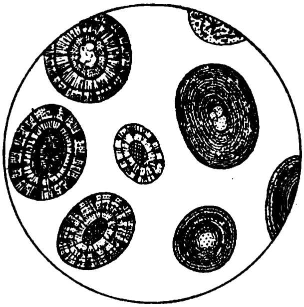


Fig. 3.

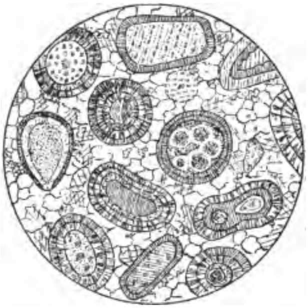


Fig. 2.—Section of oolitic granules, the formation of which can be seen at the present day, × 70. The four figures on the left show both radiated and concentric structure. These specimens were obtained from the Great Salt Lake of Utah. Their origin is ascribed by Dr. Rothpletz to the action of minute algæ. The figures on the right are from oolitic grains found on the coral-reefs of the Bahamas. They exhibit a concentric structure and are developed around nuclei, which may be grains of sand, foraminiferal shells, or other minute objects. The grain partially seen at the top on the right shows a number of branching tubes formed by burrowing algæ which are found perforating all calcareous organisms.

Fig. 3.—Section of an oolitic limestone from near Bath, also × 70. In general characters the oolitic granules agree with those formed at the present day, but they are bound together by crystalline calcite.

Many limestones contain foreign substances; and thus we get *argillaceous*, *ferruginous*, *siliceous*, and *sandy limestones*, *carbonaceous*, *glauconitic*, and *pyritous limestones*, &c. The calcium carbonate is often more or less crystallised, and when sufficiently hard to bear polishing the rock is called 'marble.' When completely crystallised we get either the pure white *statuary* or *saccharoid limestone*, or a similar material coloured by various foreign minerals which are present as impurities.

Other varieties of aqueous rocks.—In addition to the three principal classes of aqueous rocks which pass into one another by insensible gradations, we find several other materials present in much smaller quantities as stratified masses.

Beds of calcium phosphate, often made up of bones and teeth (bone-beds), occur, but are of limited thickness and extent.

Beds of iron carbonate or of iron oxide, with or without water, are by no means rare; the ferruginous materials being variously combined with calcareous, argillaceous, and arenaceous substances. In most cases it can be shown that the ferrous carbonate has replaced calcium carbonate in the rock, even the

remains of shells and other calcareous organisms being converted into iron carbonate. Some of these rocks, as at Cleveland in Yorkshire, and Scunthorpe in Lincolnshire, form very valuable iron ores. Rocks which once consisted of ferrous carbonate are often found converted into the brown hydrated ferric oxide.

Gypsum, or hydrated calcium sulphate, forms beds of considerable extent. When crystalline or nearly compact it forms the ornamental stone known as alabaster, which is distinguished from marble by its much greater softness. In clays exposed to the action of the weather, crystals of gypsum (selenite) are often formed by sulphuric acid, produced by the oxidation of pyrites, coming into contact with the calcium carbonate of fossil shells. Beds of anhydrite, which is gypsum deprived of water, also occur in some places.

Rock-salt and some allied substances are found in extensive beds in certain places.

Lastly, deposits of peat, lignite, coal, anthracite, and graphite, with others of cannel coal, and solid and liquid hydrocarbons, are found in layers sometimes of considerable thickness; while the whole substance of porous rock-masses may be impregnated with various liquid and gaseous hydrocarbons.

Varieties of coal.—Ordinary coal is more or less amorphous; it only occasionally shows something of a fibrous structure, and it has a tendency to cleave in cubical or prismatic blocks. The divisional planes often contain small films of calcite, gypsum, and iron pyrites.

The coals spoken of as 'bituminous' are those which soften or fuse when heated at a less temperature than that required for combustion; it must be remembered, however, there is nothing like bitumen in coal, and the proportion of carbon in such coals is from 80 to 90 per cent., of hydrogen 4·5 to 6 per cent., and oxygen 8 to 14 per cent.

It appears, from the researches of Liebig and other eminent chemists, that when wood and vegetable matter are buried in the earth exposed to moisture, and partially or entirely excluded from the air, they decompose slowly and evolve carbon dioxide gas, thus parting with a portion of their original oxygen. By this means they become gradually converted into lignite or wood-coal, which contains a smaller proportion of hydrogen and oxygen than wood. A continuance of decomposition changes this lignite into common or bituminous coal, chiefly by the escape of carburetted hydrogen, or the gas by which we illuminate our streets and houses. According to Bischoff, the inflammable gases which escape from coal, and are so often the cause of fatal

accidents in mines, always contain carbon dioxide, carburetted hydrogen, and nitrogen. The disengagement of all these gradually transforms ordinary or bituminous coal into anthracite.

The chemical composition of the several varieties of coal, with their relations to one another and to the vegetable tissues out of which they are formed, are illustrated in the following tables, which are based on data collected by Prof. Thorpe.

MEAN COMPOSITION OF CARBONACEOUS DEPOSITS, THE ASH BEING DEDUCTED

—	Wood	Humus	Peat	Lignite	Brown coal	Caking coal	Steam coal	Anthracite
Carbon	50·2	54·8	60·8	67·4	72·8	80·5	86·5	95·2
Hydrogen	6·2	4·8	5·9	5·6	5·4	5·3	5·2	2·5
Oxygen and Nitrogen	43·6	40·4	33·3	27·0	21·8	14·2	8·3	2·3

That the conversion of vegetable tissues into peat and coal and thence into anthracite is brought about by a diminution in the quantity of hydrogen, oxygen, and nitrogen, and an increase of the residual carbon, is shown by the following table, in which the proportion of the gaseous constituents to the carbon is calculated, the ash being omitted :—

—	Specific gravity	Carbon	Hydrogen	Oxygen and Nitrogen
Wood (average)	0·50	100	12·3	86·8
Peat (average)	0·85	100	9·7	54·7
Lignite (average)	1·04	100	8·3	40·0
Brown coal (average)	1·15	100	7·4	29·7
Common coal (average)	1·30	100	6·4	13·4
Anthracite (average)	1·50	100	2·6	2·3
Graphite (average)	2·20	100	0	0

It must be remembered, however, that while the oxygen, hydrogen, and nitrogen are passing off, a portion of the carbon goes too, not only water and ammonia being formed but carbon dioxide and various hydrocarbons. The gaseous elements, however, pass off at a greater rate than the carbon, and thus the proportion of the latter element is being continually augmented in the residual mass. The existence of occasional seams of coal almost wholly made up of the macrospores and microspores of the great cryptogams of the period will be noticed in the sequel; such beds occur in the Yorkshire and Leicestershire Coal-fields, and in many other districts. (See p. 61, fig. 66.)

The composition of the nearest modern representatives of

the coal-measure plants, and of their spores, is compared with that of the spore-coals in the following table:—

——	Lycopods	Lycopod spores	'Better bed' spore coal
Carbon	46·8	61·5	85·1
Hydrogen	6·2	8·4	3·4
Oxygen and Nitrogen .	42·1	27·7	5·2
Ash	4·9	2·4	6·3

There is an intimate connection between the extent to which the coal has in different regions parted with its gaseous contents, and the amount of disturbance which the strata have undergone.

In the eastern part of the South Wales Coal-field we find beds of ordinary or 'bituminous' coal, which further west are replaced by the harder coals containing a higher proportion of carbon and a smaller percentage of oxygen and hydrogen, and constituting the well-known 'steam-coals' of the district. Further west, in Pembrokeshire, where the disturbance of the strata has been very great, we find the coals replaced by beds of anthracite, in which almost all traces of oxygen and hydrogen have disappeared.

In Pennsylvania, the strata of coal are horizontal to the westward of the Appalachian Mountains, where Professor H. D. Rogers pointed out that they were most bituminous; but as we travel south-eastward, where they no longer remain level and unbroken, the same seams become progressively debituminised in proportion as the rocks become more bent and distorted. At first on the Ohio River the proportion of hydrogen, oxygen, and other volatile matters, ranges from forty to fifty per cent. Eastward of this line, on the Monongahela, it still approaches forty per cent., where the strata begin to experience some gentle flexures. On entering the Appalachian Mountains, where the distinct anticlinal axes begin to show themselves, but before the dislocations are considerable, the volatile matter is generally in the proportion of eighteen or twenty per cent. At length, when we arrive at some isolated coal-fields associated with the boldest flexures of the Appalachian chain, where the strata have been actually turned over, as near Pottsville, we find the coal to contain only from six per cent. of volatile matter, thus becoming a genuine anthracite.

Besides the general descriptions of the different varieties of aqueous rocks in the several petrographical works already referred to, the student will find much valuable information in the addresses of Mr. Sorby to the Geological Society in 1879–80. He will also do well to consult the memoir on 'Oceanic Deposits,' forming one of the volumes of the 'Reports of the Challenger Expedition.'

CHAPTER V

STRUCTURES PRODUCED IN AQUEOUS ROCK-MASSES DURING THEIR DEPOSITION

Forms of stratification—Original horizontality of strata—False bedding or oblique lamination—Irregularities in the accumulation of strata—Thinning-out and alteration in the characters of strata—Ripple marks, sun-cracks, footprints, tracks, trails, burrows, and worm-casts.

WHEN we study a rock-mass of aqueous origin, we find that it presents certain characters which must be the result of causes acting while its materials were being accumulated, and other features which are as certainly the consequence of changes that have taken place in the rock long subsequently to its deposition. It is the first-mentioned class of characters which we propose to consider in the present chapter.

Forms of stratification.—A series of strata sometimes consists of one of the varieties of rocks mentioned in the preceding chapter, sometimes of two or more kinds in alternating beds.

Thus, for example, in the coal districts of England, we often pass through various beds of sandstone, some of finer, others of coarser grain, some white, others of a dark colour, and below these, alternating layers of shale and sandstone or beds of shale, divisible into leaf-like laminæ, and containing beautiful impressions of plants. Then again we meet with beds of pure and impure coal, also alternating with shales and sandstones, and underneath the whole, perhaps, are beds of limestone, filled with corals and marine shells, each bed distinguishable from the others by certain fossils, or by the abundance of particular species of shells or zoophytes.

This alternation of different kinds of rock produces the most distinct stratification; and we often find beds of limestone and marl, conglomerate and sandstone, sand and clay, recurring again and again, in nearly regular sequence, throughout a series of many hundred strata. The causes which produce these phenomena are various, and may be either changes in the nature and degree of fineness of the material deposited, or interruptions in the regular course of deposition, when the layer first formed may have had time to consolidate before the next layer was spread over it, thus causing an imperfect adhesion between successive strata of the same composition. Rivers flowing into lakes and seas are found to be charged with sediment, varying in quantity, composition, colour, and grain according

to the seasons; the waters are sometimes flooded and rapid, at other periods low and feeble. Different tributaries, also, draining peculiar countries and soils—and therefore charged with peculiar sediment—are swollen at distinct periods; but all these different kinds of sediment will be deposited successively over the same area. The waves of the sea and currents also undermine the cliffs, during wintry storms, and sweep away the materials into the deep, after which a season of tranquillity succeeds, when nothing but the finest mud is spread by the movements of the ocean over the same submarine area.

It is not the object of the present work to give a description of these operations, repeated as they are year after year and century after century; but we may explain by way of illustration the manner in which some micaceous sandstones have originated, namely, those in which we see thin layers of mica dividing layers of fine quartzose sand. This arrangement of materials may be observed in recent mud deposited upon the shore near La Roche St. Bernard in Brittany, at the mouth of the Loire. The surrounding rocks are of gneiss, which, by its waste, supplies the mud; when this dries, it is found, at low water, to consist of brown laminated clay, divided by thin seams of mica. The separation of the mica in this case, or in that of micaceous sandstones, may be illustrated in the following manner. If we take a handful of quartzose sand, mixed with mica, and throw it into a clear running stream, we see the materials immediately sorted by the moving water, the grains of quartz falling almost directly to the bottom, while the plates of mica take a much longer time to sink through the water, and are carried farther down the stream. At the first instant the water is turbid, but almost immediately the flat surfaces of the plates of mica are seen all alone, reflecting a silvery light as they descend slowly, to form a distinct micaceous lamina. Although the mica is the heavier mineral of the two, it remains a longer time suspended in the fluid, owing to its greater extent of surface. It is easy, therefore, to perceive that where such mud is acted upon by a river or tidal current, the thin plates of mica will be carried farther, and not deposited in the same places as the grains of quartz; and since the force and velocity of the stream varies from time to time, layers of mica or of sand will be thrown down successively on the same area.

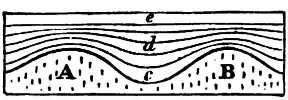
Original horizontality.—It is said generally that the upper and under surfaces of strata, or the 'planes of stratification,' are parallel. Although this is not strictly true, they make an approach to parallelism, for the same reason that sediment is usually deposited at first in nearly horizontal layers, whatever

may be the state of the floor on which the deposit rests. Yet if the sea should go down, as when there is very low tide, near the mouth of a large river where a delta has been forming, we see extensive plains of mud and sand laid dry, which, to the eye, appear perfectly level, although, in reality, they slope gently from the land towards the sea.

This tendency in newly formed strata to assume a horizontal position arises principally from the motion of the water, which forces particles of sand or mud over the bottom, and causes them to settle in hollows or depressions where they are less exposed to the force of a current than when they are resting on elevated points. The velocity of the current and the motion of the superficial waves diminish from the surface downwards, and are least in those depressions where the water is deepest.

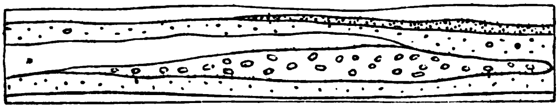
A good illustration of the principle here alluded to may be sometimes seen in the neighbourhood of a volcano, when a section, whether natural or artificial, has laid open to view a succession of various-coloured layers of sand and ashes, which have fallen in showers upon uneven ground. Thus let A B (fig. 4) be two ridges with an intervening valley. These original inequalities of the surface have been gradually effaced by beds of sand and ashes, *c*, *d*, *e*, the surface at *e* being quite level. Now, water in motion can exert this levelling power on similar materials more easily than air, for almost all stones lose in water more than a third of the weight which they have in air, the specific gravity of rocks being in general as 2½ when compared with that of water, which is taken as 1. But the buoyancy of sand or mud would be even greater in the sea, as the density of salt water exceeds that of fresh.

Fig. 4.



Yet, however uniform and horizontal may be the surface of new deposits in general, there are still many disturbing causes,

Fig. 5.



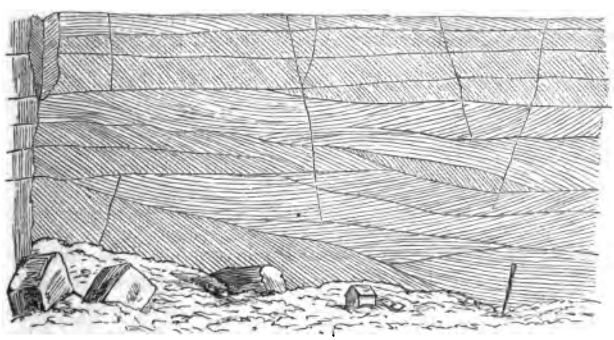
Section of strata of sandstone, grit, and conglomerate.

such as eddies in the water, and currents moving first in one and then in another direction, which frequently cause irregularities. We may sometimes follow a bed of limestone, shale,

or sandstone for a distance of many hundred yards continuously, but we generally find that, sooner or later, each individual stratum thins out, and allows the beds which were previously above and below it to meet. If the materials are coarse, as in grits and conglomerates, the same beds can rarely be traced many yards without varying in size, and often rapidly thinning out and coming to an end (see fig. 5).

False bedding or oblique lamination.—There is also another phenomenon of frequent occurrence in stratified masses. We find a series of larger strata, each of which is composed of a number of minor layers placed obliquely to the general planes of stratification. To this diagonal arrangement the name of 'false or cross bedding' or 'oblique lamination' has been given. Thus in the annexed section (fig. 6) we see many beds of loose

Fig. 6.

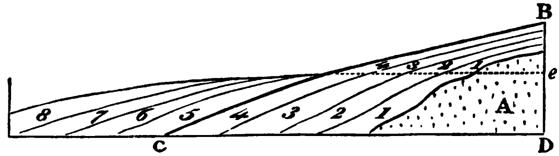


False bedding in Great Oolite. After Jukes-Brown.

sand, yellow and brown, and some of the principal planes of stratification are nearly horizontal. But the greater part of the subordinate laminæ do not conform to these planes, but have often a steep slope, the inclination being sometimes towards opposite points of the compass. When the sand is loose and incoherent, as in the case here represented, the deviation from parallelism of the slanting laminæ cannot possibly be accounted for by any rearrangement of the particles acquired during the consolidation of the rock. In what manner, then, can such irregularities be due to original deposition? We must suppose that at the bottom of shallow seas, as well as in the beds of rivers, the motions of waves, currents, and eddies often cause mud, sand, and gravel to be thrown down in heaps on particular spots instead of being spread out uniformly over a wide

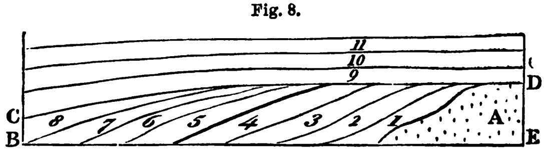
area. Sometimes, when banks are thus formed, currents may cut passages through them, just as a river forms its bed. Suppose the bank A (fig. 7) to be thus formed with a steep sloping side, and, the water being in a tranquil state, the layer of sediment

Fig. 7.



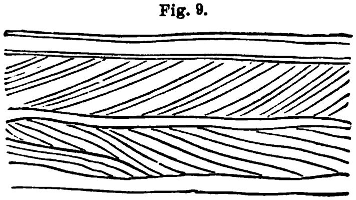
No. 1 is thrown down upon it, conforming nearly to its surface. Afterwards the other layers, 2, 3, 4, may be deposited in succession, so that the bank B C D is formed. If the current then increases in velocity, it may cut away the upper portion of this mass down to the dotted line *e*, and deposit the materials thus

Fig. 8.



removed farther on, so as to form the layers 5, 6, 7, 8. We have now the bank B C D E (fig. 8), of which the surface is almost level, and on which the nearly horizontal layers, 9, 10, 11, may then accumulate. It was shown in fig. 6 that the diagonal layers of successive strata may sometimes have an opposite slope. This is well seen in some cliffs of loose sand on the Suffolk coast. A portion of one of these is represented in fig. 9, where the layers, of which there are about six in the thickness of an inch, are composed of quartzose grains. This arrangement may have been due to the altered direction of the tides and currents in the same place.

Fig. 9.

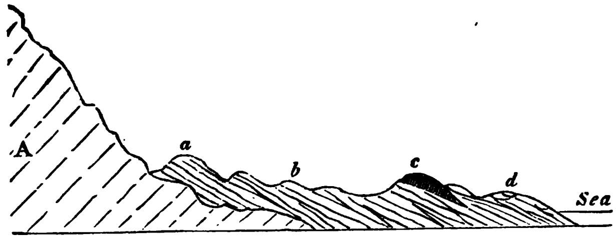


Cliff between Mismer and Dunwich.

Irregularities in the accumulation of strata.—The description above given of the slanting position of the minor layers constituting a single stratum is in certain cases appli-

cable on a much grander scale to masses several hundred feet thick, and many miles in extent. A fine example may be seen at the base of the Maritime Alps near Nice. The mountains here terminate abruptly in the sea, so that a depth of one hundred fathoms is often found within a stone's throw of the beach, and sometimes a depth of 3,000 feet within half a mile. But at certain points strata of sand, marl, or conglomerate intervene between the shore and the mountains, as in the section (fig. 10), where a vast succession of slanting beds of gravel and sand may be traced from the sea to Monte Calvo, a distance of no less than 9 miles in a straight line. The dip of these beds is remarkably uniform, being always southwards or towards the Mediterranean, at an angle of about 25°. They are exposed to view in nearly vertical precipices, varying from 200 to 600 feet in height, which bound the valley through which the river

Monte Calvo. Fig. 10.



Section from Monte Calvo to the sea by the valley of Magnan, near Nice.

A. Dolomite and sandstone of Mesozoic age.
a, *b*, *d*. Beds of gravel and sand.
c. Fine marl and sand of Ste. Madeleine, with marine (Pliocene) shells.

Magnan flows. Although, in a general view, the strata appear to be parallel and uniform, they are nevertheless found, when examined closely, to be wedge-shaped, and to thin out when followed for a few hundred feet or yards, so that we may suppose them to have been thrown down originally upon the side of a steep bank where a river or alpine torrent discharged itself into a deep and tranquil sea, and formed a delta, which advanced gradually from the base of Monte Calvo to a distance of 9 miles from the original shore. If subsequently this part of the Alps and bed of the sea were raised 700 feet, the delta would have emerged; a deep channel may then have been cut through it by the river, and the coast may at the same time have acquired its present configuration.

It is well known that the torrents and streams which now descend from the alpine declivities to the shore bring down

annually, when the snow melts, vast quantities of shingle and sand, and then, as they subside, fine mud, while in summer they are nearly or entirely dry; so that it may be safely assumed that deposits like those of the valley of the Magnan, consisting of coarse gravel alternating with fine sediment, are still in progress at many points, as, for instance, at the mouth of the Var. They must advance upon the Mediterranean in the forms of great shoals terminating in a steep talus; such being the original mode of accumulation of all coarse materials conveyed into deep water, especially where they are composed in great part of pebbles, which cannot be transported to indefinite distances by currents of moderate velocity. By inattention to facts and inferences of this kind, a very exaggerated estimate has sometimes been made of the supposed depth of the ancient ocean. There can be no doubt, for example, that the strata *a*, fig. 10, or those nearest to Monte Calvo, are older than those indicated by *b*, and these again were formed before *c*; but the vertical depth of gravel and sand in any one place cannot be proved to amount even to 1,000 feet; it may possibly be greater, yet it probably never exceeds at any point 3,000 or 4,000 feet. But were we to assume that all the strata were once horizontal, and that their present dip or inclination was due to subsequent movements, we should then be forced to conclude that a sea several miles deep had been filled up with alternate layers of mud and pebbles thrown down one upon another.

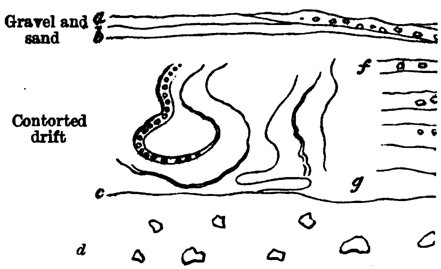
In the *fan-taluses* of the Himalaya, described by the late Mr. Drew, we have examples on a grand scale of accumulations of conglomerates and similar rocks by streams descending from mountain chains; these form great delta-like deposits with the strata, often showing considerable inclination where the mountain streams debouch upon the plains.

Irregularities in glacial formations.—When masses of ice or of frozen materials are included in a stratified mass, the gradual thawing of the ice and escape of the water may lead to great disturbance and even to crumpling of the strata, as shown in fig. 11. Similar effects are produced when masses of rock-salt or limestone are removed in solution, and even when beds of coal are removed by mining operations, giving rise to what are known to miners as 'creeps' in the overlying and underlying beds.

Cases like this must be regarded as exceptional, however, and, as a general rule, strata are originally deposited in a horizontal position, and the disturbed and contorted appearances which they exhibit are to be referred to the movements to which they have been subjected, long subsequently to their deposition.

Thinning out and alteration of the characters of strata.—When we study the stratified masses composing the earth's crust, we find that, however uniform a bed may appear to be at first sight, it is really of limited extent, and tends to 'thin out' and become lenticular in form. In the case of coarse deposits like gravels and conglomerates, the wedging out of a stratum may be very conspicuous, and can be traced in such sections as are afforded by quarries and sea-cliffs. In the case of such fine deposits as clays, and in materials of organic origin like limestones, the beds of rock may be of more persistent character and wider extent, but in no case is a stratum of absolutely indefinite extension; if traced far enough, it will be found to either thin out or, by a gradual change of mineral characters, merge in some other stratum.

Fig. 11.



Section of contorted drift overlying till, seen on left bank of South Esk, near Cortachie, in 1840. Height of section from *a* to *d*, about 50 feet.

d represents a boulder clay with blocks of stone, showing little or no traces of stratification. The beds *c*, *f*, *g* have locally undergone much disturbance, while the beds *b* and *a* have been laid down nearly horizontally.

After a bed has been deposited, a change in the direction or force of the currents may lead to its being partially washed away. The eroded surface may then be covered up by another deposit. This gives rise to the phenomenon known as contemporaneous erosion (see figs. 7 and 8, p. 38).

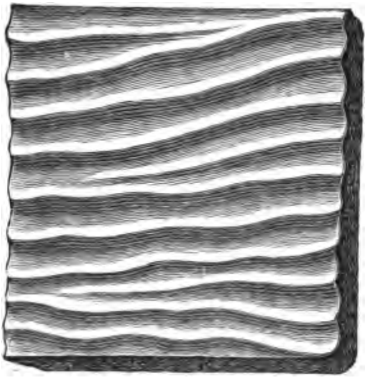
When seen in section, the appearances called 'false bedding' and contemporaneous erosion present some resemblance to the phenomena to be hereafter described as 'unconformability' and 'overlap.' The first-mentioned structures are, however, of a more or less local character, and, as we shall see in the sequel, very distinct from those important relations exhibited by rock masses over wide areas to which the name of 'unconformity' is applied.

There are many other phenomena presented by sediments

which have been accumulated under the influence of moving currents that are well worthy of attention.

Ripple marks, &c.—The ripple marks, so common on the surface of sandstones of all ages (see fig. 12), and which are so often seen on the sea-shore at low tide, seem to originate in the pushing along of sand-grains over the sea-bottom by the force of the current. This ripple is not entirely confined to the beach between high and low water-mark, but is also produced on sands which are constantly covered by water. It has been shown, by experimenting with sand in troughs of water, that rippled surfaces, with varying height and breadth of furrows, can be produced by changing the direction and force of the current. We sometimes find a surface of sandstone rock

Fig. 12.



Slab of ripple-marked (New Red) sandstone, from Cheshire.

crossed by two intersecting series of ripple marks, resulting from a change in the direction of the current. Similar undulating ridges and furrows may also be sometimes seen on the surface of drift snow and blown sand.

Ripple marks are usually an indication of a sea-beach, or of water from 6 to 10 feet deep, for the agitation caused by waves even during storms extends to no great depth. To this rule, however, there are some exceptions, and recent ripple marks have been observed at a depth of 60 or 70 feet. It has also been ascertained that currents or large bodies of water in motion may disturb mud and sand at a depth of 300 or even 450 feet.[1] Beach ripple, however, may usually be distinguished from current ripple by frequent changes in its direction. In a

[1] Darwin's *Volcanic Islands*, first edition, p. 134.

slab of sandstone, not more than an inch thick, the furrows or ridges of an ancient ripple may often be seen in several successive laminæ to run towards different points of the compass.

There are other appearances known as 'rill-marks, 'wave-marks,' 'sun-cracks,' 'rain and hail prints,' which, together with 'worm-casts,' 'burrows,' 'trails,' and foot-prints, are usually indicative of deposition in shallow water. (See figs. 531–533, pp. 367, 368).

The student will do well to take every opportunity of studying for himself the appearances presented on a sandy or muddy shore. The various phenomena exhibited are very fully discussed and their origin explained in the 'Principles of Geology,' and also in Part II. of the late Professor J. D. Dana's admirable 'Manual of Geology,' fourth edition (1895).

CHAPTER VI

ARRANGEMENT OF FOSSILS IN STRATA—MARINE, FRESHWATER, AND TERRESTRIAL DEPOSITS

Slow deposition of strata proved by fossils—Rocks formed of the remains of organisms—Diatomaceous deposits—Bog-iron ore and lake-ores of Sweden—Importance of fossils as indicating the conditions under which strata were deposited—Deep-sea deposits—Radiolarian deposits, chalk and other limestones—Distinction of freshwater from marine formations—Genera of freshwater and land shells—Rules for recognising marine shells—Alternation of marine and freshwater deposits—Terrestrial deposits and their fossils—Origin of coal and other carbonaceous rocks.

HAVING in the last chapter considered the forms of stratification so far as they are determined by the arrangement of inorganic matter, we may now turn our attention to the matter in which organic remains are distributed through stratified deposits. We should often be unable to detect any signs of stratification or of successive deposition, if the remains of particular kinds of organisms did not occur here and there at certain depths in the mass. At one level, for example, univalve shells of some one or more species predominate; at another, bivalve shells; and at a third, corals; while in some formations we find layers of vegetable matter, which have usually been derived from land plants, separating strata.

It may appear inconceivable to a beginner how mountains, several thousand feet thick, can have become full of organic remains from top to bottom; but the difficulty is removed when he reflects on the origin of stratification, as explained in the last chapter, and allows sufficient time for the accumulation of

sediment. He must never lose sight of the fact that, during the process of deposition, each separate layer was once the uppermost, and immediately in contact with the water in which aquatic animals lived. Each stratum, in fact, however far it may now lie beneath the surface, was once in the state of shingle, or loose sand or soft mud at the bottom of the sea, in which shells and other bodies easily became enveloped. The term 'fossil is applied by geologists to any mineralised fragment of an organism found in the earth's crust, or to any indication found in the rocks of the existence, while they were being deposited, of any kind of living creatures. Thus we speak not only of leaves, shells, bones, and teeth as fossils, but we apply the term equally to the casts or impressions left by these bodies, and to burrows, tracks, trails, and footprints made by living creatures, on sedimentary rocks during their deposition. Originally such organic remains were called 'extraneous fossils,' but now the adjective is dropped, and the term fossils has become synonymous with 'organic remains.'

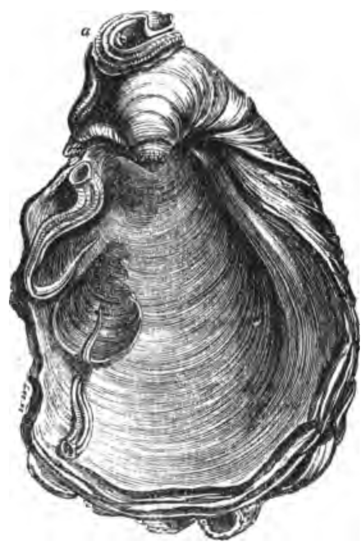
Fossils are of the greatest interest and value to the geologist, enabling him to form a judgment as to the particular conditions under which a stratum containing them must have been deposited.

Rate of deposition indicated by fossils.—By attending to the nature of these remains, we are often enabled to determine whether the deposition was slow or rapid, whether it took place in a deep or shallow sea, near the shore or far from land, and whether the water was salt, brackish, or fresh. Some limestones consist almost exclusively of corals, and in many cases it is evident that the present position of each fossil zoophyte has been determined by the manner in which it grew originally. The axis of the coral, for example, if its natural growth is erect, still remains at right angles to the plane of stratification. If the stratum be now horizontal, the round spherical heads of certain species continue uppermost, and their points of attachment are directed downwards. This arrangement is sometimes repeated throughout a great succession of strata. From what we know of the growth of similar zoophytes in modern reefs, we infer that the rate of increase was extremely slow, and some of the fossils must have flourished for years, like forest trees, before they attained so large a size. During these ages, the water must have been clear and transparent, for such corals cannot live in turbid water.

In like manner, when we see thousands of full-grown shells dispersed everywhere throughout a long series of strata, we cannot doubt that time was required for the multiplication of

successive generations; and the evidence of slow accumulation is rendered more striking from the proofs, so often discovered, of fossil bodies having lain for a time on the floor of the ocean after death, before they were embedded in sediment. Nothing, for example, is more common than to see fossil oysters in clay, with serpulæ, or barnacles (acorn-shells), or corals, and other creatures attached to the inside of the valves, so that the mollusk was certainly not buried in argillaceous mud the moment it died. There must have been an interval during which it was still surrounded with clear water, when the creatures whose remains now adhere to it grew from an embryonic to a mature state. Attached shells which are merely external, like some of the serpulæ (*a*) in fig. 13, may often have grown upon an oyster or other shell while the animal within was still living; but if they are found on the inside, it could only happen after the death of the inhabitant of the shell which affords the support. Thus, in fig. 13 it will be seen that two serpulæ have grown on the interior, one of them exactly on the place where the adductor muscle of the *Gryphæa* (a kind of oyster) was fixed.

Fig. 13.

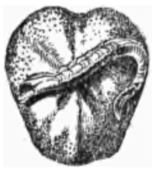


Fossil *Gryphæa* (nat. size), covered both on the outside and inside with fossil serpulæ.

Some fossil shells, even if simply attached to the *outside* of others, bear full testimony to the conclusion above alluded to, namely, that an interval elapsed between the death of the creature to whose shell they adhere and the burial of the same in mud or sand. The sea-urchins, or *Echini*, so abundant in white chalk, afford a good illustration of this remark. It is well known that these animals, when living, are invariably covered with spines supported by rows of tubercles. These last are only seen after the death of the sea-urchin, when the spines have dropped off. In fig. 15 a living specimen of *Spatangus*, common on our coast, is represented with one half of its shell stripped of the spines.

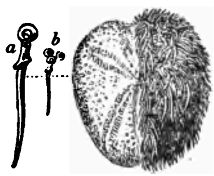
In fig. 14 a fossil of the genus *Micraster* found in the white chalk of England shows the naked surface which the individuals of this species exhibited when denuded of their spines. The full-grown *Serpula*, therefore, which now adheres externally,

Fig. 14.



Serpula attached to a fossil *Micraster*, ⅓ nat., from the chalk.

Fig. 15.

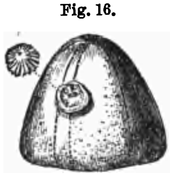


Recent *Spatangus*, ¼ nat., with the spines removed from one side.
b. Spine and tubercles, nat. size.
a. The same magnified.

could not have begun to grow till the *Micraster* had died and the spines became detached.

Now the series of events here attested by a single fossil may be carried a step farther. Thus, for example, we often meet with a sea-urchin (*Ananchytes* or *Echinocorys*) in the chalk, (see fig. 16), which has the lower valve of a *Crania*, a genus of *Brachiopoda*, fixed to it. The upper valve (*b*, fig. 16) is almost invariably wanting, though occasionally found in a perfect state of preservation in the chalk at some distance. In this case, we see clearly that the sea-urchin first lived from youth to age, then died and lost its spines, which were carried away. Then the young *Crania* adhered to the bared shell, grew and perished in its turn; after which the upper valve was separated from the lower before the *Ananchytes* became enveloped in chalky mud. The rate of accumulation of the chalk must, therefore, have been excessively slow.

Fig. 16.

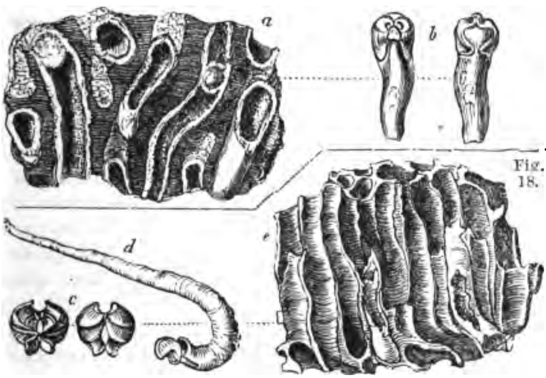


a. *Ananchytes* (*Echinocorys*), from the chalk, with lower valve of *Crania* attached, ⅓ nat.
b. Upper valve of *Crania* detached.

It may be well to mention one more illustration of the manner in which single fossils may sometimes throw light on a former state of things, both in the bed of the ocean and on some adjoining land. We meet with many fragments of wood bored by ship-worms, at various depths in the clay on which London is built. Entire branches and stems of trees, several feet in length, are sometimes found drilled all over by the holes of these borers, the tubes and shells of the mollusk still remaining in the cylindri-

cal hollows. In fig. 18, *e*, a representation is given of a piece of recent wood pierced by the *Teredo navalis*, L., or common ship-worm, which destroys wooden piles and ships. When the cylindrical tube *d* has been extracted from the wood, the valves are seen at the larger or anterior extremity, as shown at *c*. In like manner, a piece of fossil wood (*a*, fig. 17) has been perforated by a kindred but distinct genus, the *Teredina* of Lamarck. The calcareous tube of this mollusk was united and as it were soldered on to the valves of the shell (*b*), which therefore cannot be detached from the tube, like the valves of the recent *Teredo*. The wood in this fossil specimen is now

Fig. 17.



Fossil and recent wood drilled by perforating Mollusca.

Fig. 17. *a*. Fossil wood from London clay, bored by *Teredina*, ½ nat. size.
b. Shell and tube of *Teredina personata*, Lam. sp., the right-hand figure the ventral, the left the dorsal view.

Fig. 18. *e*. Recent wood bored by *Teredo*, ½ nat. size.
d. Shell and tube of *Teredo navalis*, L., fróm the same.
c. Anterior and posterior view of the valves of same detached from the tube, nat. size.

converted into a stony mass; but it must once have been buoyant and floating in the sea, when the *Teredinæ* lived upon and perforated it. Again, before the infant colony settled upon the drift wood, part of a tree must have been floated down to the sea by a river, uprooted, perhaps, by a flood, or torn off and cast into the waves by the wind; and thus our thoughts are carried back to a prior period, when the tree grew for years on dry land, enjoying a fit soil and climate.

The present rate of accumulation of deep-sea sediment is exceedingly slow, as is proved by the growths of coral that occur on electric cables. The corals grow at great depths very much

more quickly than the accumulation of the foraminiferal ooze. But rapid accumulation of some sediments must have taken place formerly, for tree stems standing erect are found in strata of coal, sand, and grit which gathered around them.

Minuteness of some of the organisms which build up great rock-masses.—It has been already remarked that there are rocks in the interior of continents, at various depths in the earth, and at great heights above the sea, almost entirely made up of the remains of zoophytes and mollusca. Such masses may be compared to modern coral-reefs and oyster-beds; and, as in their case, the rate of increase must have been extremely gradual. But there are certain deposits in the earth's crust, now proved to have been derived from plants and animals of which the organic origin was not at one time suspected, even by naturalists. Great surprise was created half a century ago by the discovery of Professor Ehrenberg, of Berlin, that a kind of siliceous material, called tripoli, was entirely composed of millions of the remains of organic beings, which were formerly referred to microscopic Infusoria, but which are now known to be plants. They abound in rivulets, lakes, and ponds in England and other countries, and are termed Diatomaceæ. The substance alluded to has long been well known in the arts, under the name of Infusorial Earth or Mountain Meal, and is used in the form of powder for polishing stone and metal. It has been procured, among other places, from Bilin, in Bohemia, in which place a single stratum, extending over a wide area, is no less than 14 feet thick. This stone, when examined under high powers of the microscope, is found to consist of the siliceous tests of the Diatomaceæ figured on the next page, united together without any visible cement. It is difficult to convey an idea of their extreme minuteness; but Ehrenberg estimates that in the Bilin tripoli there are 41,000 millions of individuals of the *Gallionella distans*, Ehb., (see fig. 20) in every cubic inch (which weighs about 220 grains), or about 187 millions in a single grain. At every stroke, therefore, that we make with this polishing powder, several millions, perhaps tens of millions, of perfect fossils are crushed to atoms.

A well-known substance, called bog-iron ore, often met with in peat-mosses, has been shown by Ehrenberg to consist of innumerable articulated threads, of a yellow-ochre colour, composed of silica, argillaceous matter, and peroxide of iron. These threads are the remains of a minute microscopic plant, called *Didymohelix ferruginea*, Ehb. sp. (fig. 19), associated with the siliceous remains of other freshwater algæ. Layers of this iron ore occurring in Scotch peat bogs are often called 'the pan'; similar beds of iron ore which have been formed of vegetable

organisms are found at the bottom of certain lakes in Sweden, and occur between the basalts of Antrim, and these are of considerable economical value.

It is clear that much time must have been required for the accumulation of strata to which countless generations of Diatomaceæ and similar microscopic algæ have contributed their remains; and these discoveries lead us naturally to suspect that other deposits, of which the materials have been supposed to be inorganic, may in reality be composed chiefly of microscopic organic bodies. That this is the case with the white chalk has often been imagined, and is now proved to be the fact. It has, moreover, been lately discovered that the chambers into which these Foraminifera are divided are actually often filled with thousands of well-preserved organic bodies (see figs. 27, 28), which abound in every minute grain of chalk,

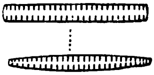
Fig. 19.

Didymohelix ferruginea, Ehb. sp.

Fig. 20.

Gallionella distans, Ehb.

Fig. 21.



Bacillaria paradoxa, Gmel. *a.* Front view. *b.* Side view.

and are especially apparent in the white coating of flints, often accompanied by innumerable needle-shaped spiculæ of sponges.

The dust we tread upon was once alive!—BYRON.

How faint an idea does this exclamation of the poet convey of the real wonders of nature! for here we discover proofs that the calcareous and siliceous dust of which whole hills are composed has not only been once alive, but almost every particle—albeit invisible to the naked eye—still retains the organic structure which, at periods of time incalculably remote, was impressed upon it by the powers of life.

Importance of fossils as indicating the conditions under which strata were deposited.—It is a well-known fact that peculiar forms of mollusca, corals, crustaceans, &c., are confined to certain depths in the ocean; some characterise shallow water between tide-marks, others are found in moderately deep water, and others, again, only in the very deepest parts of the ocean. If, then, we find in a particular stratum an assemblage of organisms which we recognise as always occurring at a given depth of water in our existing seas, we may fairly conclude that the stratum containing

the assemblage of fossils must have been deposited in a similar depth of water. Caution, of course, is required in applying this reasoning—seeing that in most cases the organisms found as fossils in rock masses are not identical but only closely related to those found in the sea at the present time.

Deep-sea deposits.—Besides the shells, corals, fish, &c., that have long been known as characterising the littoral, shallow

Fig. 22.

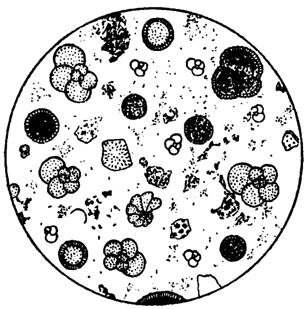


Fig. 23.

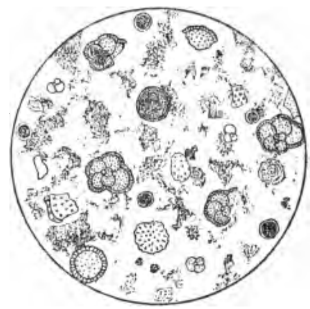


Fig. 22.—Globigerina ooze from the North Atlantic Ocean, dredged from a depth of 1,990 fathoms (× 70). The mass is seen to be made up of the calcareous shells of Globigerina and other Foraminifera, entire or broken, with fragments of larger organisms, and numerous minute calcareous particles, which are shown much more highly magnified in figs. 27 and 28.

Fig. 23.—Washings from the white chalk of Kent (also × 70), showing similar organisms to those found in the Globigerina ooze.

Fig. 24.

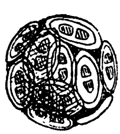


Fig. 25.

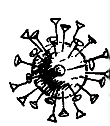


Fig. 26.

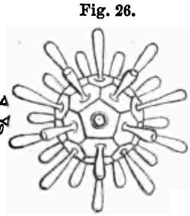


Fig. 27.

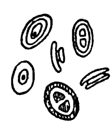


Fig. 28.

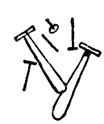


Fig. 24.—*Coccosphere* found floating on the ocean surface—a very minute organism (Calcareous alga ?), × 1,000.

Figs. 25, 26.—Two forms of *Rhabdospheres*. Similar minute organism from the ocean surface, × 1,000. (These three figures are taken from the 'Challenger' Reports.)

Fig. 27.—Isolated *Coccoliths*, which build up *Coccospheres*, and are found both in the Globigerina ooze and the chalk (see figs. 22 and 23), × 1,000.

Fig. 28.—Isolated *Rhabdoliths*, which build up *Rhabdospheres*, and are found both in the Globigerina ooze and the chalk (see figs. 22 and 23), × 1,000.

water, and deep-water parts of the ocean, we have now become acquainted—by the explorations carried on by the 'Challenger' and other surveying vessels—with organisms that live in the

abysmal recesses of the ocean, at depths down to nearly 5,000 fathoms. It is interesting to note that among the stratified rocks we find many examples of materials made up of the remains of organisms like those found in the deeper parts of the ocean.

In the chalk we have an example of a rock almost entirely made up of the calcareous shells of Foraminifera (Globigerina, &c.) with numerous small bodies, Coccoliths and Rhabdoliths, supposed to be the remains of calcareous algæ (see figs. 22–28).

In the Barbadoes Earth, we have an ooze made up of the siliceous skeletons of Radiolarians precisely similar to the material dredged up from great depths in the Pacific and Indian Oceans (see figs. 29–30).

Fig. 29.

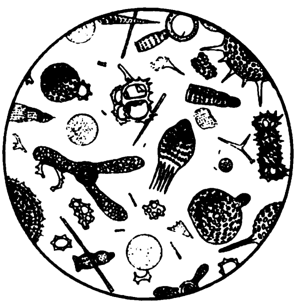


Fig. 30.

Fig. 29.—Radiolarian ooze from the Pacific Ocean, depth 2,425 fathoms, almost wholly made up of the remains of the siliceous skeletons of Radiolarians, × 70.

Fig. 30.—The Barbadoes Earth, a siliceous rock of Tertiary age, almost entirely made up of similar organisms (Radiolarians), × 70.

In the white earth of Richmond, Virginia, we have a material almost identical with the white diatomaceous ooze of the Antarctic Ocean, which is made up of the siliceous frustules of microscopical algæ (see fig. 31). Similar freshwater algæ are found building up white siliceous deposits at the bottom of lakes in this and other countries (see fig. 32).

At the greatest depths, a reddish or chocolate-coloured clay of great fineness—often containing the teeth and bones of marine animals, and curious nodules composed of iron and manganese oxides—is found covering the ocean floors.

Freshwater deposits and their fossils.—Strata, whether deposited in salt or fresh water, have the same forms; but the embedded fossils are very different in the two cases, because the aquatic animals which frequent lakes and rivers are, as a rule,

distinct from those inhabiting the sea. In the northern part of the Isle of Wight formations of marl and limestone, more than 50 feet thick, occur, in which the shells are of extinct species. Yet we recognise their freshwater origin, because they are of the same genera as those now abounding in ponds, lakes, and rivers, either in our own country or in warmer latitudes.

In many parts of France, as in Auvergne, there occur strata of limestone, marl, and sandstone hundreds of feet thick, which contain exclusively freshwater and land shells, together with the remains of terrestrial quadrupeds. The number of land shells scattered through some of these freshwater deposits is exceedingly great; and there are districts in Germany where the rocks contain scarcely any other fossils than snail-shells,

Fig. 31.

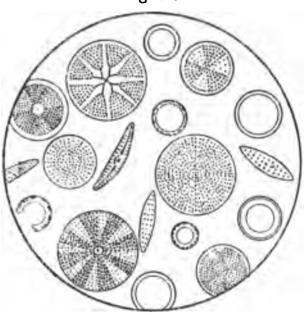


Fig. 32.

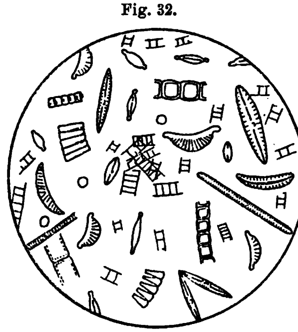


Fig. 31.—Marine forms of *Diatomaceæ* (unicellular algæ with siliceous skeletons) found at the bottom of the Antarctic Ocean (Diatomaceous ooze), and in certain siliceous rocks like the Tertiary White Earth of Richmond, Virginia ($\times$ 250).

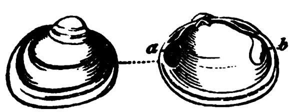
Fig. 32.—Freshwater forms of *Diatomaceæ*, found in rivers and lakes, and also making up siliceous rocks known as 'mountain-meal,' 'Kieselguhr,' 'tripoli,' &c. See also figs. 20 and 21.

(*Helix*); as, for instance, the limestone on the left bank of the Rhine, between Mayence and Worms, at Oppenheim, Findheim, Budenheim, and other places. In order to account for this phenomenon, the geologist has only to examine the small deltas of torrents which enter the Swiss lakes when the waters are low, such as the newly formed plain where the Kander enters the Lake of Thun. He there sees sand and mud strewn over with innumerable dead land-shells, which have been brought down from the valleys in the Alps in the preceding spring, during the melting of the snows. Again, if we search the sands on the borders of the Rhine, in the lower part of its course, we find countless land-shells mixed with others of species belonging to lakes, stagnant pools, and marshes. These organisms have

been washed away from the alluvial plains of the great river and its tributaries, some from mountainous regions, others from the low country.

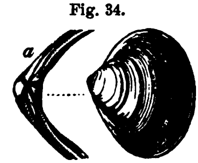
Although freshwater formations are often of great thickness, yet they are usually very limited in area when compared with marine deposits, just as lakes and estuaries are of small dimensions in comparison with seas.

Fig. 33.



Cyclas (Sphærium) corneus, Sow.; living and fossil, nat. size.

Fig. 34.



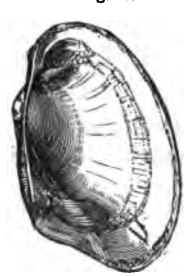
Cyrena (Corbicula) fluminalis, Müll.; fossil, Grays, Essex, and living in the Nile, nat. size.

The absence of many fossil forms usually met with in marine strata affords a useful negative indication of the freshwater origin of a formation. For example, there are no sea-urchins, no corals, no chambered shells, such as the nautilus, nor microscopic foraminifera in lacustrine or fluviatile deposits. In distinguishing the latter from formations accumulated in the sea,

Fig. 35.

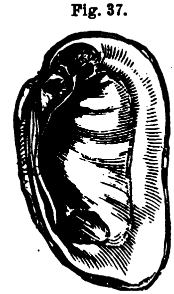
Anodonta Cordieri, D'Orb. Paris, ½.

Fig. 36.



Anodonta latimarginata, Lea.; recent. Bahia, ½.

Fig. 37.



Unio littoralis, Lam.; recent. Auvergne, ½.

we are chiefly guided by the forms of the mollusca. In a freshwater deposit, the number of individual shells is often as great as in a marine stratum, if not greater; but there is a smaller variety of species and genera. This might be anticipated from the fact that the genera and species of recent freshwater and land shells are few when contrasted with the marine.

Only a very small number of genera of bivalve shells inhabit

fresh water. Among these last, the four most common forms, both recent and fossil, are *Cyclas* (*Sphærium*), *Cyrena*, *Unio*, and *Anodonta* (see figures 33–37).

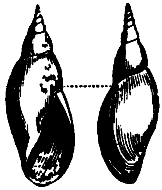
Fig. 38.

Gryphæa incurva, Sow. (*G. arcuata*, Lam.): upper valve. Lias, nat. size. Marine.

Fig. 39.

Planorbis euomphalus, Sow.; fossil. Isle of Wight, ⅔.

Fig. 40.



Limnæa longiscata, Brong.; fossil. Isle of Wight, ½.

Fig. 41.

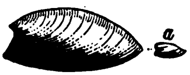
Paludina vivipara. Brand; living and fossil, nat. size.

Lamarck divided the bivalve mollusca into the *Dimyaria*, or those having two large muscular impressions in each valve, as

Fig. 42.

Succinea amphibia, Drap. (S. putris, L.); fossil. Loess, Rhine, nat. size.

Fig. 43.



Ancylus velletia (*A. elegans*), Sow.; fossil. Isle of Wight.

Fig. 44.

Valvata piscinalis, Müll.; fossil. Grays, Essex.

Fig. 45.

Physa hypnorum, L.; recent. Isle of Wight, nat. size.

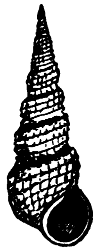
a b in the Cyclas, fig. 33, and Unio, fig. 37, and the *Monomyaria* such as the oyster and scallop, in which there is only one of these impressions, as seen in fig. 38. Now, as none of these

last, or the unimuscular bivalves, are freshwater,[1] we may at once presume a deposit containing any of them to be marine.[2]

Fig. 46.

Auricula, recent. Ava, ¼.

Fig. 47.

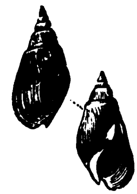


Cerithium funatum, Mant.; fossil. Isle of Wight, nat. size.

Fig. 48.

Physa columnaris, Desh.; fossil. Paris basin, ½.

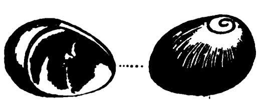
Fig. 49.



Melanopsis buccinoidea, Ferr.; recent. Asia, nat. size.

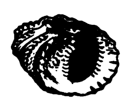
The univalve shells most characteristic of freshwater deposits are *Planorbis*, *Limnæa*, and *Paludina* (*Vivipara*). But to these are occasionally added *Physa*, *Succinea*, *Ancylus*, *Valvata*, *Melanopsis*, *Melania*, *Potamides*, and *Neritina* (see figs. 39-49), the last four being usually found in estuaries.

Fig. 50.



Neritina globulus, Def. Paris basin, nat. size.

Fig. 51.



Nerita granulosa, Desh. Paris basin, ½.

Fig. 52.

Potamides cinctus, Sow Paris basin, ⅔.

Some naturalists include *Neritina* (fig. 47) and the marine *Nerita* (fig. 51) in the same genus, it being scarcely possible to distinguish the two by good generic characters. But, as a general rule, the fluviatile species are smaller, smoother, and more globular than the marine; and they have never, like the *Neritæ*, the inner margin of the outer lip toothed or crenulated. (Compare figs. 50 and 51.)

[1] The freshwater Mulleria, which when young has two muscular impressions, has only one in the adult state, thus forming a single exception to the rule.

[2] It must be remembered, however, that marine shells are occasionally found living in brackish water, and sometimes in water that is nearly fresh. Thus oysters and cockles are sometimes found in water with but little salt; in these cases, however, the dwarfed and imperfectly developed character of the shells indicates the abnormal conditions under which they lived.

The Potamides inhabit the mouths of rivers in warm latitudes, and are distinguishable from the marine Cerithia by their orbicular and multispiral opercula. The genus Auricula (fig. 46) is both marine and freshwater, frequenting swamps and marshes within the influence of the tide.

The terrestrial shells are all univalves. The most important genera among these, both in a recent and fossil state, are *Helix* (fig. 53), *Cyclostoma* (fig. 54), *Pupa* (fig. 55), *Clausilia* (fig. 56), *Bulimus* (fig. 57), *Glandina*, and *Achatina*.

Fig. 53.

Helix turonensis, Desh.; Faluns, Touraine, nat. size.

Fig. 54.

Cyclostoma elegans, Müll.; Loess, nat. size.

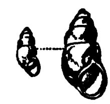
Fig. 55.

Pupa tridens, Drap.; Loess, nat. size.

Fig. 56.

Clausilia bidens, Drap.; Loess, nat. size.

Fig. 57.



Bulimus lubricus, Müll.; Loess, Rhine.

Ampullaria (fig. 58) is another genus of shells, inhabiting rivers and ponds in hot countries. Many fossil species formerly referred to this genus, and which have been met with chiefly in marine formations, are now considered by conchologists to belong to *Natica* and other marine genera.

All univalve shells of land and freshwater species, with the exception of *Melanopsis* (fig. 49), and *Achatina*, which show a slight indentation, have entire mouths; and this circumstance may often serve as a convenient rule for distinguishing freshwater from marine strata; since if any univalves occur of which the mouths are not entire, we may presume that the formation is marine. The aperture is said to be entire in such shells as the freshwater *Ampullaria* (fig. 58) and the land shells (figs. 53–57), when its outline is not interrupted by an indentation or notch, such as that seen at *b* in *Ancillaria* (fig. 60); or is not prolonged into a canal, as that seen at *a* in *Pleurotoma* (fig. 59).

Fig. 58.

Ampullaria glauca, from the Jumna, ½.

The mouths of a large proportion of the marine univalves have these notches or canals, and almost all the species are carnivorous; whereas nearly all gastropoda having entire mouths are plant-eaters, whether the species be marine, freshwater, or terrestrial.

There is, however, a genus which affords an occasional exception to one of the above rules. The *Potamides* (fig. 52), a subgenus of Cerithium, although provided with a short canal, comprises some species which inhabit salt, others brackish, and others fresh water, and they are said to be all plant-eaters.

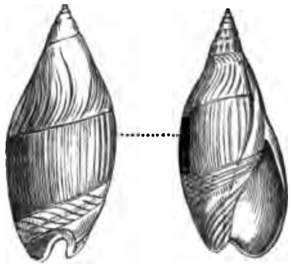
Among the fossils very common in freshwater deposits are the shells of *Cypris*, a minute bivalve crustaceous animal. Many minute living species of this genus swarm in lakes and stagnant pools in Great Britain; but their shells are not, if considered separately, conclusive as to the freshwater origin of a deposit, because the majority of species in another kindred genus of the same order, the *Cytherina* of Lamarck, inhabit salt water; and, although the animal differs slightly, the shell is scarcely distinguishable from that of the *Cypris*.

Fig. 59.

a

Pleurotoma exorta, Brand. Upper and Middle Eocene, Barton and Bracklesham, nat. size.

Fig. 60.



b

Ancillaria subulata, Sow. Barton clay. Eocene, nat. size.

Freshwater fossil plants.—The seed-vessels and stems of *Chara*, a genus of calcareous plants, are very frequent in freshwater strata. The seed-vessels were called, before their true nature was known, gyrogonites, and, like many similar fragments of calcareous algæ, were supposed to be foraminiferous shells. (See fig. 61, *a*.)

The *Charæ* inhabit the bottom of lakes and ponds, and flourish mostly where the water is charged with calcium carbonate.

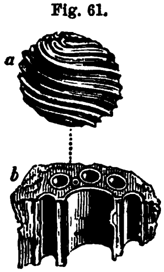
Their seed-vessels are covered with a very tough integument, containing calcium carbonate, to which circumstance we may attribute their abundance in a fossil state. The annexed figure (fig. 62) represents a branch of one of many new species found by Professor Amici in the lakes of Northern Italy. The stems, as well as the seed-vessels, of these plants occur both in modern shell marl and in ancient freshwater formations.

They are generally composed of a large central tube surrounded by smaller ones, the whole stem being divided at certain intervals by transverse partitions or joints. (See *b*, fig. 61.)

It is not uncommon to meet with layers of vegetable matter, impressions of leaves, and branches of trees, in strata containing freshwater shells; and we also find occasionally the teeth and bones of land quadrupeds, of species now unknown. The manner in which such remains are sometimes carried by rivers into lakes, especially during floods, has been fully treated of in the 'Principles of Geology.'

Freshwater and marine fish.—The remains of fish are occasionally useful in determining the freshwater origin of strata. Certain genera, such as *Cyprinus* (carp), *Perca* (perch), *Esox* (pike), *Cobitis* (loach), and *Lebias*, are peculiar to fresh water.

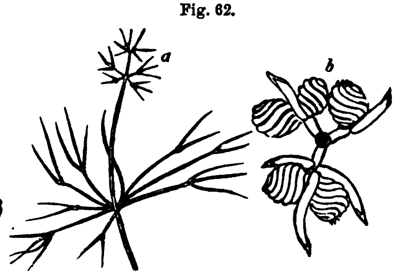
Fig. 61.



Chara medicaginula, Brong.; fossil. Upper Eocene, Isle of Wight.

a. Seed-vessel magnified 20 diameters.
b. Stem magnified.

Fig. 62.



Chara elastica, Amici; recent. Italy.

a. Sessile seed-vessel between the divisions of the leaves of the female plant.
b. Magnified transverse section of a branch with five seed-vessels, seen from below upwards.

Other genera contain some freshwater and some marine species, as *Cottus*, *Mugil*, and *Anguilla* (eel). The rest are either common to rivers and the sea, as the salmon; or are exclusively characteristic of salt water. The above observations respecting fossil fishes are applicable only to the modern or tertiary deposits; for in the more ancient rocks the forms depart so widely from those of existing fishes that it is very difficult, at least in the present state of science, to derive any positive information from ichthyolites respecting the nature of the water in which strata were deposited.

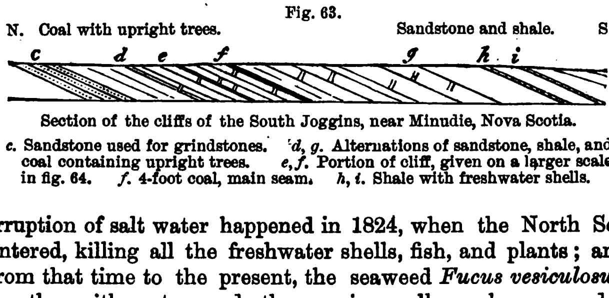
The alternation of marine and freshwater formations, both on a small and large scale, are facts well ascertained in geology. When it occurs on a small scale, it may have arisen from the successive occupation of certain spaces by river water and the

sea; for in the flood season the river forces back the ocean, and freshens it over a large area, depositing at the same time its sediment; after which the salt water again returns, and, on resuming its former place, brings with it sand, mud, and marine shells.

There are also lagoons at the mouths of many rivers, as the Nile and Mississippi, which are divided by bars of sand from the sea, and which are filled with salt and fresh water by turns. They often communicate exclusively with the river for months, years, or even centuries; and then, a breach being made in the bar of sand, they are for long periods filled with salt water.

The Lym-Fjord in Jutland offers an excellent illustration of analogous changes; for, in the course of the last thousand years, the western extremity of this long frith, which is 120 miles in length, including its windings, has been four times fresh and four times salt, a bar of sand between it and the ocean having been often formed and removed. The last

Fig. 63.



Section of the cliffs of the South Joggins, near Minudie, Nova Scotia.

c. Sandstone used for grindstones. *d, g.* Alternations of sandstone, shale, and coal containing upright trees. *e, f.* Portion of cliff, given on a larger scale in fig. 64. *f.* 4-foot coal, main seam. *h, i.* Shale with freshwater shells.

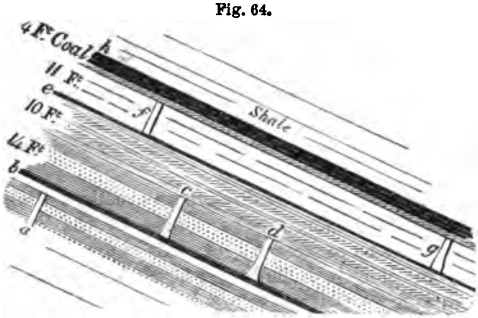
irruption of salt water happened in 1824, when the North Sea entered, killing all the freshwater shells, fish, and plants; and from that time to the present, the seaweed *Fucus vesiculosus*, together with oysters and other marine mollusca, has succeeded the *Cyclas*, *Limnea*, *Paludina*, and *Chara*.

But changes like these in the Lym-Fjord, and those before mentioned as occurring at the mouths of great rivers, will only account for some cases of marine deposits of partial extent and thickness resting on freshwater strata. When we find, as in the south-east of England, a great series of freshwater beds, 1,000 feet thick, resting upon marine formations and again covered by other rocks, such as the cretaceous, also more than 1,000 feet thick, and of deep-sea origin, we shall find it necessary to seek for a different explanation of the phenomena.

Terrestrial deposits and their fossils.—Although deposits formed on the land are rare, they are not quite unknown to geologists. Beds of peat, lignite, and coal consist of the remains of land plants which in many cases can be shown to have grown

in the spot where they are now found. In some cases the trunks of trees are still found attached to their roots and rising through the strata above them as shown in the diagrams of the South Joggins Coal-field of Nova Scotia. (See figs. 63, 64.)

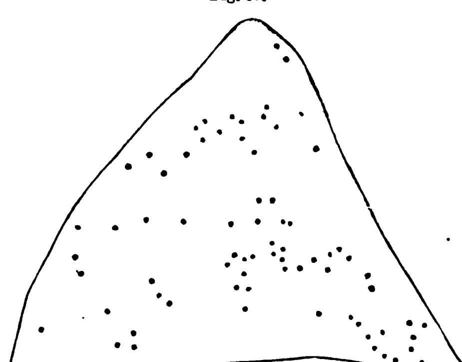
Fig. 64.



Erect fossil trees, *a*, *c*, *d*, *f*, *g*. Coal-measures, Nova Scotia (after Sir J. W. Dawson).

In some cases, great numbers of trunks of trees have thus been found in connection with the masses of vegetable matter forming a bed of coal. Thus in South Staffordshire a seam of

Fig. 65.

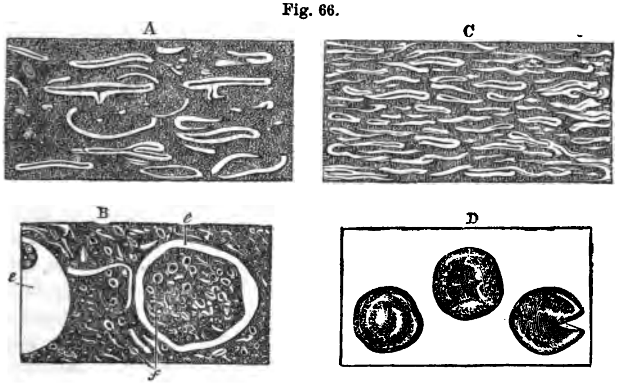


Ground plan of a fossil forest, Parkfield Colliery, near Wolverhampton, showing the position of 73 trees in a quarter of an acre.

coal was laid bare in the year 1844, in what is called an open work at Parkfield Colliery, near Wolverhampton. In the space of about a quarter of an acre the stumps of no less than seventy-three trees with their roots attached appeared, as shown in the

annexed plan (fig. 65), some of them more than 8 feet in circumference. The trunks, broken off close to the root, were lying prostrate in every direction, often crossing each other. One of them measured 15, another 30 feet in length, and others less. They were invariably flattened to the thickness of one or two inches, and converted into coal. Their roots formed part of a stratum of coal 10 inches thick, which rested on a layer of clay 2 inches thick, below which was a second forest, resting on a 2-foot seam of coal. Again, five feet below this, was a third forest with large stumps of *Lepidodendra*, *Calamites*, and other trees. In one instance it was found possible to determine the direction of the prevailing wind, at the time when the trees were growing, from the bending of all the trunks in one direction.

Fig. 66.



A. '*Better-Bed*' Coal, from a portion unusually full of Macrospores, which are here shown in transverse section.
B. Same coal, section parallel with bedding; showing Macrospores, *e*, and Microspores, *f*; the latter (which are here represented somewhat too large) appear as bright rings enclosing a dark spot.
C. Australian 'White Coal,' showing Macrospores in transverse section.
D. External view of Macrospores separated from the 'White Coal.'

All these figures are enlarged about 16 diameters.

The dirt-beds of the Isle of Portland (see figs. 345, 348, p. 291) offer examples of similar terrestrial deposits.

While many beds of coal consist of the compressed stems, leaves, and other parts of plants, some particular bands are almost entirely made up of their spores or organs of fructification. Professor Huxley has ascertained that in the Better-Bed coal of Lowmoor, near Bradford (see A, B, fig. 66), the spores (macrospores and microspores) of the great plants of the Carboniferous age constitute a very large portion of the rock, and this is also the case with the recent 'White Coal' of Australia (see C, D, fig. 66).

It must be remembered, however, that these 'sporė-coals' are somewhat exceptional, though all coals probably contain spores as well as other portions of the plants of which they are made up. Some beds of coal, moreover (like the cannel coals), were certainly not formed of plants growing *in situ*, but must have consolidated from masses of black carbonaceous mud like those produced by the bursting of peat bogs. Coal seams also alternate with strata containing marine, freshwater, or brackish-water fossils, showing that, even when accumulated on land, this land was but little above the sea-level—like the islands forming portions of deltas. Strata accumulated under such conditions as these are spoken of as 'estuarine deposits.'

The student must bear in mind that while some seams of coal were certainly formed from plants undergoing decay upon the spot where they grew—as is indicated by the existence of 'underclays' or old soils beneath them, containing the roots of plants—other beds of coal would seem to have been produced from masses of drifted vegetable matter that have accumulated in hollows, have been covered up by other strata, and have then slowly undergone chemical change.

The purity of the coal itself, or the absence from it of earthy particles and sand, throughout areas of vast extent, is a fact which appears very difficult to explain when we attribute each coal-seam to a vegetation growing in swamps. It has been asked how, during river inundations capable of sweeping away the leaves of ferns and the stems and roots of *Sigillariæ* and other trees, could the waters fail to transport some fine mud into the swamps? One generation after another of tall trees grew with their roots in mud, and their leaves and prostrate trunks formed layers of vegetable matter, each of which was afterwards covered with mud since turned to shale. Yet the coal itself, or altered vegetable matter, remained all the while uncontaminated by earthy particles. The difficulty will be removed if we consider what is now taking place in deltas. The dense growth of reeds and herbage which encompasses the margins of forest-covered swamps in the valley and delta of the Mississippi is such that the fluviatile waters, in passing through them, are filtered and made to clear themselves entirely before they reach the areas in which vegetable matter accumulates; and this accumulation may go on for centuries, forming coal if the climate be favourable. There is little chance of the intermixture of earthy matter in such cases. Thus in the large submerged tract called the 'Sunk Country,' near New Madrid, forming part of the western side of the valley of the Mississippi, erect trees have been standing ever since the year

1811–12, killed by the great earthquake of that date; lacustrine and swamp plants have been growing there in the shallows, and several rivers have annually inundated the whole space, and yet have been unable to carry in any sediment within the outer boundaries of the morass, so dense is the marginal belt of reeds and brushwood. It may be affirmed that, generally, in the 'cypress swamps' of the Mississippi no sediment mingles with the vegetable matter accumulated there from the decay of trees and semi-aquatic plants. As a singular proof of this fact, it may be mentioned that whenever any part of a swamp in Louisiana is dried up, during an unusually hot season, and the wood is set on fire, pits are burnt into the ground many feet deep, or as far down as the fire can descend, without meeting with water, and it is then found that scarcely any residuum of earthy matter is left. At the bottom of all these 'cypress swamps' a bed of clay is found, with roots of the tall cypress (*Taxodium distichum*, Rich.), just as the underclays of the coal are filled with *Stigmaria*.

The separation from the carbonaceous masses in the earth's crust of water, ammonia, carbon dioxide, and the various hydrocarbons must be attended with a great diminution in the bulk of the mass. Unger calculated that it would require a thickness of 8·76 feet of vegetable matter to make a bed of coal one foot in thickness.

With regard to the time taken for the growth of the materials forming carbonaceous deposits, Heer has estimated that the growth of one foot of peat requires about a century.

There is at Petrosene in Transylvania a bed of coal of tertiary age ninety feet in thickness. If the above estimates be correct, the ninety feet of coal would represent 788 feet of vegetable matter, the accumulation of which would require 78,800 years!

The facts of the distribution of the forms of vegetable and animal life in the ocean have been much more fully made known by the various deep-sea exploring expeditions. The '"Challenger" Report on Oceanic Deposits,' by Dr. John Murray and Prof. A. Renard, contains much valuable information illustrating the origin of limestones and other marine deposits. The final volume of the Reports contains a useful summary of all the facts which were ascertained by the 'Challenger' and the deep-sea exploring expedition concerning the distribution of life forms at various depths in the ocean. On the subject of the formation of coal, the student will find much valuable information in 'Coal: its History and Uses,' by Professors Green, Miall, Thorpe, Rücker, and Marshall, 1878.

CHAPTER VII

CONSOLIDATION AND SUBSEQUENT ALTERATIONS OF STRATA AND PETRIFACTION OF ORGANIC REMAINS

Consolidation of strata—Concretionary structures—Jointed structure—Mineralisation of organic remains—Formation of casts—Wonderful preservation of the internal structures of fossil organisms—Petrifactions and incrustations—Pseudo-fossils.

HAVING spoken in the preceding chapters of the characters of sedimentary formations, both as dependent on the deposition of inorganic matter and the distribution of fossils, we may next treat of the consolidation of stratified rocks, and the petrifaction of embedded organic remains.

Consolidation of strata.—In the case of some calcareous rocks, solidification takes place at the time of deposition. But there are many deposits in which a cementing process comes into operation long afterwards. We may sometimes observe, where the water of ferruginous or calcareous springs has flowed through a bed of sand or gravel, that iron or lime compounds have been deposited in the interstices between the grains or pebbles, so that in certain places the whole has been bound together into a stone, the same set of strata remaining in other parts loose and incoherent.

Proofs of a similar cementing action are seen in a rock at Kellaways in Wiltshire. A peculiar sandy stratum, belonging to the Jurassic formation of geologists, may be traced through several counties, the sand being for the most part loose and unconsolidated, but becoming stony near Kellaways. In this district there are numerous fossil shells which have decomposed, having for the most part left only their casts. The calcareous matter hence derived has evidently served, at some former period, as a cement to the siliceous grains of sand, and thus a solid sandstone has been produced. If we take fragments of many sandy or argillaceous rocks, retaining the casts of shells, and plunge them into dilute acid, we see the mass immediately breaks up into sand or mud; the cement of calcium carbonate, derived from the shells, having been dissolved by the acid.

Traces of impressions and casts are often extremely faint. In some loose sands of recent date we meet with shells in so advanced a stage of decomposition as to crumble into powder when touched. It is clear that water percolating such strata may soon remove the calcareous matter of the shell; and, unless

circumstances cause the calcium carbonate to be again deposited, the grains of sand will not be cemented together; in which case no memorial of the fossil will remain.

It is evident that silica and calcium carbonate are widely diffused in small quantities through the waters which permeate the earth's crust, and thus a stony cement is often supplied to sand, pebbles, or any fragmentary mixture. In some conglomerates, like the pudding-stone of Hertfordshire (a Lower Eocene deposit), pebbles of flint and grains of sand are united by a siliceous cement so firmly that, if a block be broken, the fracture passes as readily through the pebbles as through the cement.

It is probable that many strata become solid owing to the pressure of the superincumbent rocks under which they have been buried. The consolidation of rocks is often largely due to the chemical action of the water and gases which penetrate the minutest pores of rocks, and the consequent deposition of calcium carbonate, iron carbonate or oxide, silica, and other minerals previously held in solution.

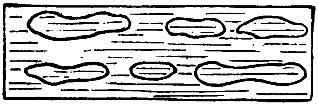
Most stones on being freshly quarried are found to be soft and easily cut, but harden by exposure. The marl recently deposited at the bottom of Lake Superior, in North America, is soft and often filled with freshwater shells; but if a piece be taken up and dried, it becomes so hard that it can only be broken by a smart blow of the hammer. If the lake, therefore, were drained, such a deposit would be found to consist of strata of marlstone, like that observed in many ancient European formations, and, like them, containing freshwater shells.

Concretionary structure.—It is probable that some of the heterogeneous materials which rivers transport to the sea may at once set under water, like the artificial mixture called pozzolana, which consists of fine volcanic sand, to which a small quantity of lime has been added. This substance hardens, and becomes a solid stone in water, and was used by the Romans in constructing the foundations of buildings in the sea. Consolidation, in such cases, is brought about by the chemical reaction which takes place between the silica and lime. After deposition particles of similar chemical composition seem often to exert a mutual attraction for each other, and segregate in particular spots, forming lumps, nodules, and concretions. Thus, in many argillaceous deposits there are calcareous balls, or spherical concretions, ranged in layers parallel to the general stratification; an arrangement which took place after the shale or marl had been thrown down in successive laminæ; but these laminæ are often traceable through the concretions, remaining parallel to those of

the surrounding unconsolidated rock (see fig. 67). Such nodules of argillaceous limestone have often a shell or other foreign body in the centre. In some cases these nodules exhibit a series of ramifying cracks which are usually filled with calcite. Nodules of this kind are called 'Septaria.' The calcareo-argillaceous nodules often contain much ferrous carbonate, and sometimes constitute valuable iron-ores.

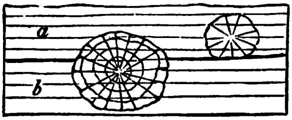
Among the most remarkable examples of concretionary structure are those described by Professor Sedgwick as abounding in the magnesian limestone of the north of England. The spherical balls are of various sizes, from that of a pea to a diameter of several feet, and they have both a concentric and radiated structure, while at the same time the laminæ of original deposition pass uninterruptedly through them. In some cliffs this limestone resembles a great irregular pile of cannonballs. Some of the globular masses have their centre in one stratum, while a portion of their exterior passes through to the stratum above or below. Thus the larger spheroid in the an-

Fig. 67.



Calcareous nodules in Lias, seen in section.

Fig. 68.



Spheroidal concretions in magnesian limestone.

nexed section (fig. 68) passes from the stratum *b* upwards into *a*. In this instance we must suppose the deposition of a series of minor layers, first forming the stratum *b*, and afterwards the incumbent stratum *a*; then a movement of the particles took place, and the calcium and magnesium carbonates separated from the more impure and mixed matter forming the still unconsolidated parts of the stratum. Crystallisation, beginning at the centre, must have gone on forming concentric coats around the original nucleus without interfering with the laminated structure of the rock.

By similar processes of segregation and crystallisation in masses of mixed materials, the structures known as 'cone-in-cone,' 'beef,' 'stylolites,' &c., have evidently been formed. The crystallising material in these cases is usually either calcium carbonate or ferrous carbonate, and the clay or other foreign materials are caught up and included in the crystals. In the Fontainebleau sandstone we have a mixture of sand and calcium carbonate, and in the midst of the rock, groups of large and perfect crystals

of calcite are formed, which are crowded with sand grains caught up by the growing crystals. The curious structures known to geologists as 'botryoidal,' 'mammillated,' &c., are due to similar selective and crystallising agencies operating in the midst of great rock-masses.

The rocks of the earth's crust have often been subjected to great pressure for long periods of time from the accumulation of thousands of feet of rock above them. Such pressures are capable of bringing about the coherence of finely divided materials like clay; this is illustrated by the process of making lead pencils by subjecting powdered graphite to pressure, and by the very suggestive experiments of M. Spring, who has shown how many powdered materials may be converted into hard and coherent masses by the action of pressure alone.

Analogous effects of consolidation and condensation have arisen when the solid parts of the earth's crust have been forced in various directions by those mechanical movements hereafter to be described, by which strata have been bent, broken, and raised above the level of the sea. Rocks of more yielding materials must often have been forced against others previously consolidated, and may thus, by compression, have acquired a new structure. Finely laminated and cleaved structures in rocks are produced and intensified by the action of pressure.

Jointed structure.—Joints are natural fissures which often traverse rocks in straight and well-determined planes, more or less at right angles to the planes of bedding or stratification. If a sufficient number cross each other, the whole mass of rock is split into symmetrical blocks, and they afford to the quarryman the greatest aid in the extraction of blocks of stone. The faces of the joints are for the most part smoother and more regular than the surfaces of true strata. The joints are straight-cut fissures, sometimes slightly open, and often pass not only through layers of successive deposition, but also through balls of limestone or other matter, which have been formed by concretionary action since the original accumulation of the strata, and in the case of conglomerates even through quartz pebbles. Such joints, therefore, must often have resulted from one of the last changes superinduced upon sedimentary deposits.

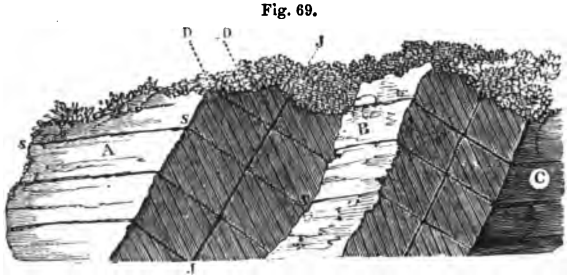
In the annexed diagram (fig. 69), the flat surfaces of rock, A, B, C, represent exposed faces of joints, to which the walls of other joints, J, J, are parallel. S S are the lines of stratification; D D are lines of slaty cleavage, which intersect the rock at a considerable angle to the planes of stratification.

In the Swiss and Savoy Alps, as Mr. Bakewell has remarked, enormous masses of limestone are cut through so regularly by

nearly vertical partings, and these joints are often so much more conspicuous than the planes of stratification, that an inexperienced observer will almost inevitably confound them, and suppose the strata to be perpendicular in places where in fact they are almost horizontal. Jukes observed joints in recently formed coral rock in the Australian and other reefs. Joints are due to contraction of strata during consolidation, and also to great movements which take place in the earth's crust.

Joints in aqueous rock-masses are supposed to be analogous to the partings which separate volcanic and plutonic rocks into cuboidal and prismatic masses. On a small scale we see clay and starch when dried split into similar shapes; this is often caused by simple contraction, whether the shrinking be due to the evaporation of water, or to a change of temperature. It is well known that sandstones and other rocks expand by the

Fig. 69.



Stratification, joints, and cleavage.
(From Murchison's 'Silurian System,' p. 245.)

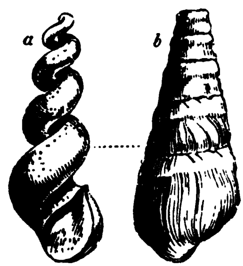
application of heat, and then contract again on cooling; and there can be no doubt that large portions of the earth's crust have, in the course of past ages, been subjected again and again to very different degrees of heat and cold. These alternations of temperature have probably contributed largely to the production of joints in rocks.

In many countries where masses of basalt rest on sandstone or shale, the aqueous rock has for the distance of several feet from the point of junction assumed a columnar structure similar to that of the igneous mass. In like manner some hearthstones, after exposure to the heat of a furnace without being melted, have separated into prismatic blocks.

Mineralisation of organic remains.—The changes which fossil organic bodies have undergone since they were first embedded in rocks throw much light on the consolidation of strata. In some modern deposits, shells and other organic

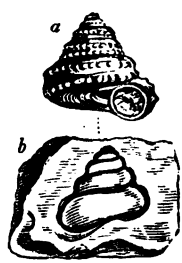
remains have been scarcely altered in the course of centuries, having simply lost a part of their animal matter. Such slightly altered organisms are spoken of as sub-fossil forms. But in other cases the shell may have disappeared, and left an impression only of its exterior, and perhaps also a mould of its interior; in other cases again we find a reproduction of the shell itself in some new material taking the place of the original matter which has been removed. These different forms of fossilisation may easily be understood if we examine the mud recently thrown out from a pond or canal in which there are shells. If the mud be argillaceous, it acquires consistency on drying, and on breaking open a portion of it we find that each shell has left impressions of its external form. If we then remove the shell itself, we find within a solid nucleus of clay, having the form of the interior of the shell. This form is often very different from that of the

Fig. 70.



Chemnitzia Heddingtonensis, Sow.; sp., ½ nat., and cast of the same. Coral Rag.

Fig. 71.



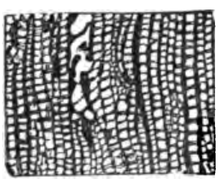
Pleurotomaria anglica, Sow.; sp., nat., and cast, Lias, ½ nat.

outer shell. Thus a cast such as *a*, fig. 70, commonly called a fossil screw, would never be suspected by any one but a conchologist to be the internal shape of the fossil univalve, *b*, fig. 70. Nor should we have imagined at first sight that the shell *a* and the cast *b*, fig. 71, belong to one and the same fossil. The reader will observe in the last-mentioned figure (*b*, fig. 71), that an empty space shaded dark, which the *shell itself* once occupied, now intervenes between the enveloping stone and the cast of the smooth interior of the whorls. In such cases the shell has been dissolved and the component particles removed by water percolating the rock. If the nucleus were taken out, a hollow mould would remain, on which the external form of the shell with its tubercles and striæ, as seen in *a*, fig. 71, would be found embossed. Now, if the space alluded to between the nucleus and the impression, instead of being left empty, has been filled up with calcareous spar, flint, pyrites, or other mineral, we then

obtain from the mould an exact reproduction both of the external and internal form of the original shell. In this manner silicified casts of shells have been formed; and if the material of the nucleus happen to be incoherent, or soluble in acid, we can then procure in flint an empty shell, which in shape is the exact counterpart of the original. This cast may be compared to a bronze statue, representing merely the superficial form, and not the internal organisation; but there is another description of petrifaction by no means uncommon, and of a much more wonderful kind, which may be compared to certain anatomical models in wax, where not only the outward forms and features, but the nerves, blood-vessels, and other internal organs, are also shown. Thus we find corals, originally calcareous, in which not only the general shape, but also the minute and complicated internal organisation, is retained in flint.

Such a process of fossilisation is still more remarkably exhibited in fossil wood, in which we often perceive not only the rings of annual growth, but all the minute vessels and medullary rays. Many of the minute cells and fibres of plants, and even those spiral vessels which in the living vegetable can only be discovered by the microscope, are preserved. Among many instances of the kind may be mentioned a fossil tree, seventy-two feet in length, found at Gosforth, near Newcastle, in sandstone strata associated with coal. By cutting a transverse slice so thin as to transmit light, and magnifying it about fifty-five times, the structure as seen in fig. 72 is exhibited. A texture equally minute and complicated has been observed in the wood of large trunks of fossil trees found in the Craigleith quarry, near Edinburgh, where the stone was not siliceous, but consisted chiefly of calcium carbonate. The parallel rows of vessels here seen are the rings of annual growth, but in one part they are imperfectly preserved, the wood having probably decayed before the mineralising matter had penetrated to that portion of the tree.

Fig. 72.



Transverse section of a tree from the coal measures, magnified 55, showing texture of wood.[1]

In attempting to explain the process of fossilisation in such cases, we may first assume that strata are very generally permeated by water charged with minute portions of calcareous, siliceous, and other earths in solution. In what manner they

[1] Witham, 'Fossil Vegetables,' 1831. Plate IV. fig 1.

become so impregnated will be afterwards considered. If an organic substance is exposed in the open air to the action of the sun and rain, it will in time decay, or be resolved into its component elements, consisting usually of oxygen, hydrogen, nitrogen, and carbon, which pass into the atmosphere as water, carbon dioxide, and ammonia. But if the same substance be submerged in water, it will decompose more gradually; and if buried in earth, still more slowly; as in the familiar example of wooden piles or other buried timber. Now, if as fast as each particle is set free by decomposition, a particle of calcium carbonate, silica, or other mineral is at hand ready to be precipitated, we may imagine this inorganic matter to take the place just before left unoccupied by the organic molecule. In this manner a cast of the interior of certain vessels may first be taken, and afterwards the more solid walls of the same may decay and suffer a like transmutation. Yet when the whole is petrified, it may not form one homogeneous mass of stone. Some of the original ligneous, osseous, or other organic elements may remain mingled in certain parts, or the fossilising substance itself may be differently coloured at different times, or so crystallised as to reflect light differently, and thus the texture of the original body may be faithfully exhibited.

The student may perhaps ask whether, on chemical principles, we have any ground to expect that mineral matter will be thrown down precisely in those spots where organic decomposition is in progress. The following interesting experiments may serve to illustrate this point. Professor Göppert, of Breslau, with a view of imitating the natural process of fossilisation, steeped a number of animal and vegetable substances in waters, some holding siliceous, others calcareous, others metallic matter in solution. He found that in the period of a few weeks, or sometimes even days, the organic bodies thus immersed were mineralised to a certain extent. Thus, for example, thin vertical slices of deal, taken from the Scotch fir (*Pinus sylvestris*, L.), were immersed in a moderately strong solution of sulphate of iron. When they had been thoroughly soaked in the liquid for several days, they were dried and exposed to a red heat until the vegetable matter was burnt up and nothing remained but iron oxide, which was found to have taken the form of the deal so exactly that casts even of the dotted vessels peculiar to this family of plants were distinctly visible under the microscope.

The exact reproduction of the minute internal structures of organisms is doubtless facilitated by the extreme slowness with which the changes take place. The molecules of the animal

and vegetable tissues are one by one broken up and removed in a gaseous state, and a particle of mineral matter takes its place. The highest powers of our microscopes are far from reaching the ultimate chemical molecules, and hence we are not surprised to find the individual cells and vessels of plants, and even the markings in these cells and vessels, exquisitely reproduced in mineral matter; and all the minute structures in corals, shells, and bones preserved with the same delicacy. Even flowers and the wings of insects may sometimes be found exquisitely preserved in a fossil state.

The chief substances which replace vegetable and animal remains, and thus form fossils or true petrifactions, are calcium carbonate (in the forms of the minerals calcite and aragonite), ferrous carbonate (which is often converted into various iron oxides more or less hydrated), iron disulphide (in the forms known as pyrites and marcasite), and silica (in the forms of opal, chalcedony, and quartz). But besides these four very common fossilising materials almost any mineral may be found replacing the substance of an animal or vegetable organism, or occupying the empty space left by its removal.

These true 'fossils' must not be confounded with the *incrustations* of organic bodies by calcium carbonate which are found in districts where calcareous springs abound, and which are often erroneously spoken of as 'petrifactions.' In Derbyshire, Auvergne, and other similar districts, leaves, twigs, birds' nests, and even larger structures may be found coated over and preserved by a thin stalagmite-like layer of calcium carbonate, which has been deposited from a so-called 'petrifying spring.' Indeed, such springs are sometimes employed for coating artificial substances, and producing casts or reproductions of objects of art.

We must also be on our guard against treating as fossils those accidental representations of natural objects which sometimes occur in rocks. Thus in irregular flints and other concretions a more or less fanciful resemblance to twigs or nuts, fingers or toes, and various other parts of plants and animals may sometimes be traced. When there is no ground for believing that such resemblances are more than accidental, we speak of the object as a 'pseudo-fossil.'

There are some pseudo-fossils, however, which it is extremely difficult to distinguish from real fossils. On exposed rock-surfaces we often find a curious 'mimic vegetation' (like the frost on a window-pane), known as dendrites (figs. 73–75), and these have often been taken for the remains of plants. Similar structures are found enclosed within the so-called 'moss-agates.'

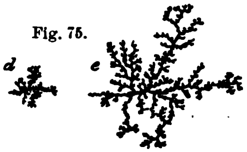
On the surface of slates at Wicklow, Ireland, peculiar mark-

ings supposed to be the remains of plants, bryozoa or some other organisms, have been found, and have received the name of *Oldhamia*, two distinct species being recognised. Professor Sollas has shown grounds, however, for believing that these

Fig. 73.

Fig. 74.

Fig. 75.

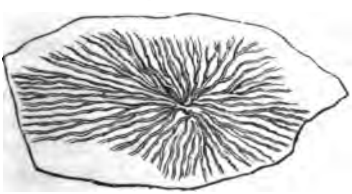


Dendrites on surfaces of flint hatchets in the drift of St. Acheul, near Amiens.
a. Natural size. *b*. Natural size. *c*. Magnified. *d*. Natural size. *e*. Magnified.

markings are not really of organic origin, but may be 'pseudo-fossils,' formed by a peculiar wrinkling of the surfaces of a fine mud in drying. There are many tracks and burrows formed by worms and other creatures living on muddy and sandy shores, that have been mistaken for fossil plants—as has been shown by Nathorst.

The most remarkable example of a pseudo-fossil, however, is the famous '*Eozoon canadense*,' Daw., which was long regarded

Fig. 76.



Oldhamia radiata, Forbes.
Wicklow, Ireland.

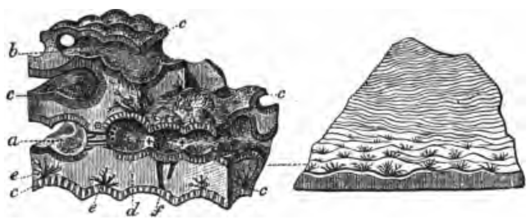
Fig. 77.

Oldhamia antiqua, Forbes.
Wicklow, Ireland.

as the oldest known fossil. This consists of layers of white calcite and of a green silicate so remarkably intergrown as to simulate in a very striking manner the internal structure of certain organisms (foraminifera). Many very able naturalists have

been deceived by the curious resemblances of 'eozoon' to real organisms. In the accompanying drawing the following structures may be noted: (1) The arrangement of cells like those of foraminiferal shells; (2) the rod-like connecting processes resembling 'stolons;' (3) the curious series of branching tubuli, like what is known in the 'intermediate skeleton' of those organisms; and (4) the apparently finely perforated shell substance ('nummuline layer') can all be made out under the microscope. In spite of these striking resemblances, however, the most recent investigations of microscopists and mineralogists

Fig. 78. Fig. 79.



Eozoon canadense,' Daw. (after Carpenter). A pseudo-fossil. The structures supposed to be organic are indicated in these two figures, by Dr. Carpenter, which give a diagrammatic representation of what was thought to be foraminiferal structure.

Fig. 78. *a*. Chambers of lower tier communicating at +, and separated from adjoining chambers at ⊙ by an intervening septum, traversed by passages. *b*. Chambers of an upper tier. *c*. Walls of the chambers, traversed by fine tubules ('Nummuline layer'). (These tubules pass with uniform parallelism from the inner to the outer surface, opening at regular distances from each other.) *d*. Intermediate skeleton, composed of homogeneous shell substance, traversed by stoloniferous passages (*f*), connecting the chambers of the two tiers. *e*. Canal system in intermediate skeleton, showing the arborescent sarcodic prolongations. (Fig. 79 shows these bodies in a decalcified state.) *f*. Stoloniferous passages.

Fig. 79. Decalcified portion of natural rock, showing the supposed *canal system* and the several layers. Natural size.

leave little room for doubt that the structures are all of inorganic origin and of an imitative character.

These and similar cases illustrate the necessity of great caution on the part of the geologist in discriminating between true fossils showing real organic structures and the curiously imitative structures which sometimes result from the action of segregative and crystallising forces acting within rock-masses.

The chemical processes involved in the consolidation of strata, in the formation of nodules, casts, &c., and in the petrifaction of organic remains, are described in Professor Haughton's 'Manual of Geology,' Lecture III., and in Dana's 'Manual of Geology,' 4th edition, 1895. The mineralisation of plant remains has been very ably discussed by Professor Solms-Laubach in the introductory chapter to his 'Fossil Botany' (English edition, 1891).

CHAPTER VIII

ELEVATION OF STRATA ABOVE THE SEA—HORIZONTAL AND INCLINED STRATIFICATION—FAULTING

Why the position of marine strata, above the level of the sea, should be referred to the rising up of the land, not to the going down of the sea—Strata of deep-sea and shallow-water origin alternate—Also marine and freshwater beds and old land surfaces—Vertical, inclined, and folded strata—Anticlinal and synclinal curves—Dip and strike—Structure of the Jura—Various forms of outcrop—Synclinal strata forming ridges—Connection of fracture and flexure of rocks—Inverted strata—Faults described—Superficial signs of the same obliterated by denudation—Great faults the result of repeated movements—Arrangement and direction of parallel folds of strata—Unconformability—Overlap—Dip-slopes and escarpments—Outliers and inliers.

Land has been raised, not the sea lowered.—It has been already stated that the aqueous rocks containing marine fossils extend over wide continental tracts, and are seen in mountain chains rising to great heights above the level of the sea. Hence it follows, that what is now dry land was once under water. But if we admit this conclusion, we must imagine, either that there has been a general lowering of the waters of the ocean, or that the solid rocks, once covered by water, have been raised up bodily out of the sea, and have thus become dry land. The earlier geologists, finding themselves reduced to this alternative, embraced the former opinion, assuming that the ocean was originally universal, and had gradually sunk down to its actual level, so that the present islands and continents were left dry. It seemed to them far easier to conceive that the water had gone down than that solid land had risen upwards into its present position. It was, however, impossible to invent any satisfactory hypothesis to explain the disappearance of so enormous a body of water throughout the globe, it being necessary to infer that the ocean had once stood at whatever height marine shells might be detected. It moreover appeared clear, as the science of Geology advanced, that certain areas on the globe had been successively sea, land, estuary, and then sea again, to finally become once more habitable land; and that they remained in each of these states for considerable periods. In order to account for such phenomena, without admitting any movement of the land itself, we are required to imagine several retreats and returns of the ocean; and even then our theory applies merely to cases where the marine strata composing the dry land are horizontal, leaving unexplained those more common

instances where strata are inclined, curved, or placed on their edges, and evidently not in the position in which they were first deposited.

Geologists, therefore, were at last compelled to have recourse to the doctrine that the solid land has been repeatedly moved upwards or downwards, so as permanently to change its position relatively to the sea. There are several distinct grounds for preferring this conclusion. First, it will account equally for the position of those elevated masses of marine origin in which the stratification remains horizontal, and for those in which the strata are disturbed, broken, inclined, or vertical. Secondly, it is consistent with human experience that land should rise gradually in some places and be depressed in others. Such changes have actually occurred in our own days, and are now in progress, having been accompanied in some cases by violent convulsions, while in others they have proceeded so insensibly as to have been ascertainable only by the most careful scientific observations, made at considerable intervals of time. On the other hand, there is no evidence from human experience of a rising or lowering of the sea's level in any region, and the ocean cannot be raised or depressed in one place without its level being changed all over the globe.

The vast bulk of the oceans as compared with that of the land rising above the sea-level renders it improbable that great changes in the relative position of land and water can be due to changes in the sea-level. At the same time, it must be remembered that minor alterations in the relations of land and sea may be due to local variations in the sea-level; for it has been shown that the attraction of the land-masses and other causes prevent the ocean level being that of a true sphere.

These preliminary remarks will prepare the reader to understand the great theoretical interest attached to all facts connected with the position of strata, whether horizontal or inclined, curved or vertical.

Now the first and most simple appearance is where strata of marine origin occur above the level of the sea in horizontal position. Such are the strata which we meet with in the south of Sicily, filled with shells for the most part of the same species as those now living in the Mediterranean. Some of these rocks rise to the height of more than 2,000 feet above the sea. Other mountain masses might be mentioned, composed of horizontal strata of high antiquity, which contain fossil remains of animals wholly dissimilar to any now known to exist. In the south of Sweden, for example, near Lake Wener, the beds of some of the oldest fossiliferous deposits, called Silurian and Cambrian

by geologists, occur in as level a position as if they had recently formed part of the delta of a great river, and been left dry on the retiring of the annual floods.

Instead of imagining that such fossiliferous rocks were always at their present level, and that the sea was once high enough to cover them, we suppose them to have constituted the ancient bed of the ocean, and to have been afterwards uplifted to their present height. This idea, however startling it may at first appear, is quite in accordance, as before stated, with the analogy of changes now going on in certain regions of the globe. Thus in parts of Sweden, and the shores and islands of the Gulf of Bothnia, proofs have been obtained that the land is experiencing, and has experienced for centuries, a slow upheaving movement.[1]

It appears, from the observations of Mr. Darwin and others, that very extensive regions of the continent of South America have been undergoing slow and gradual upheaval, by which the level plains of Patagonia, covered with recent marine shells, and the Pampas of Buenos Ayres, have been raised above the level of the sea. On the other hand, the gradual sinking of the west coast of Greenland, for the space of more than 600 miles from north to south, during the last four centuries, has been established by the observations of a Danish naturalist, Dr. Pingel. And while these proofs of continental elevation and subsidence, by slow and insensible movements, have been brought to light, the evidence has been daily strengthened of continued changes of level effected by violent convulsions in countries where earthquakes are frequent.

Mr. Darwin has also inferred that, in those parts of the Pacific and Indian Oceans where circular coral islands (atolls) and barrier reefs abound, there is a slow and continued sinking of the submarine mountains on which the masses of coral are based, while there are other areas where the land is on the rise, and where coral has been upheaved far above the sea-level.

The long submerged river valleys known as *fiords* in Scandinavia and as *firths* in this country bear striking testimony to the fact that on many coasts subsidence has taken place. These long winding valleys are quite different from any features that are produced by marine denudation; they have evidently been formed by the erosion of the streams which still occupy their higher and unsubmerged portions.

Along our coasts we find numerous submerged forests, only visible at low water, having the trunks of the trees erect and

[1] See 'Principles of Geology,' 1867, p. 814.

their roots attached to them and still spreading through the ancient soil as when they were living. They occur in too many places, and sometimes at too great a depth, to be explained by a mere change in the level of the tides, although, as the coasts waste away and alter in shape, the height to which the tides rise and fall is always varying, and the level of high tide at any given point may, in the course of many ages, differ by several feet or even fathoms. It is this fluctuation in the height of the tides, and the erosion and destruction of the sea-coast by the waves, that makes it exceedingly difficult for us in a few centuries, or even perhaps in a few thousand years, to determine whether there is a change by subterranean movement in the relative level of sea and land.

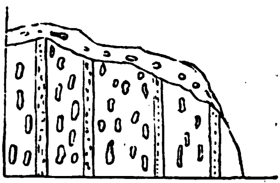
We often behold, as on the coasts of Devonshire and Pembrokeshire, facts which appear to lead to opposite conclusions. In one place is a raised beach with marine littoral shells, and in another immediately adjoining may be a submerged forest.

Alternations of marine and freshwater strata.—It has been shown in the sixth chapter that there is such a difference between land, freshwater, and marine fossils as to enable the geologist to determine whether particular groups of strata were formed at the bottom of the ocean or in estuaries, rivers, or lakes. If surprise was at first created by the discovery of marine corals and shells at the height of several miles above the sea-level, the imagination was afterwards not less startled by observing that in some successive strata composing the earth's crust, with a thickness amounting to thousands of feet, were comprised formations of littoral as well as of deep-sea origin, of beds of brackish or even of purely freshwater formation, and of others containing vegetable matter or coal which accumulated on ancient land. In these cases we as frequently find freshwater beds below a marine series, or shallow water under those of deep-sea origin, as the reverse. Thus in boring an Artesian well in London, we pass through a marine clay (the London clay), and then reach, at the depth of several hundred feet, a shallow-water and fluviatile sand (the Woolwich and Reading beds) beneath which comes the white chalk originally formed in a deep sea. Or, if we bore vertically through the marine Lower Greensand of Surrey, we come upon a freshwater formation many hundreds of feet thick, called the Wealden, such as is seen in Kent and Surrey, and this is known in its turn to rest on other purely marine beds. In like manner, in various parts of Great Britain we sink vertical shafts through lacustrine deposits of great thickness, and come upon coal, which was formed by the growth of plants on an ancient land-surface.

Vertical, inclined, and curved strata.—It has been stated that marine strata of different ages are sometimes found at a considerable height above the sea, yet retaining their original horizontality; but this state of things is quite exceptional. As a general rule, strata are inclined or bent in such a manner as to imply that their original position has been altered.

The most unequivocal evidence of such a change is afforded by their standing up vertically showing their edges, which is by no means a rare phenomenon, especially in mountainous countries. Thus we find in Scotland, on the southern skirts of the Grampians, beds of conglomerate alternating with thin layers of fine sand, all placed vertically to the horizon. When De Saussure first observed certain conglomerates in a similar position in the Swiss Alps, he remarked that the pebbles, being for the most part of an oval shape, had their longer axes parallel to the planes of stratification (see fig. 80). From this he inferred that such strata must, at first, have been horizontal, each oval pebble having settled at the bottom of the water, with its flatter side parallel to the horizon. Some few, indeed, of the rounded stones in a conglomerate occasionally afford an exception to the above rule, for the same reason that in a river's bed, or in a shingle beach, some pebbles rest on their ends or edges; these having been shoved against or between other stones by a wave or current so as to assume this position.

Fig. 80.



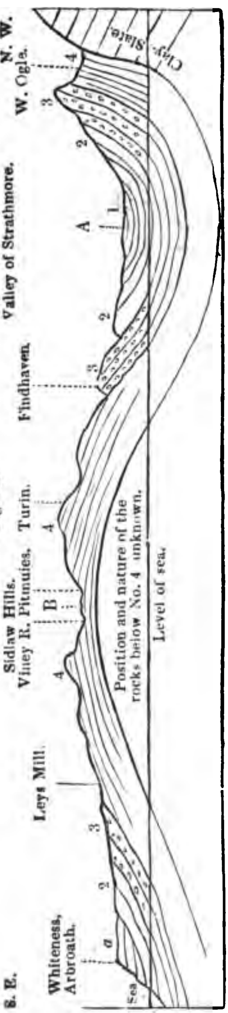
Vertical conglomerate and sandstone.

Anticlinal and synclinal curves.—Vertical strata, when they can be traced continuously upwards or downwards for some depth, are almost invariably seen to be parts of great curves, which may have a diameter of a few yards or of several miles. We will first describe two curves of considerable regularity, which occur in Forfarshire, extending over a country twenty miles in breadth, from the foot of the Grampians to the sea near Arbroath (fig. 81).

The mass of strata exhibited may be 2,000 feet in thickness, consisting of red and white sandstone and various coloured shales, the beds being distinguishable into four principal groups—namely: No. 1, red marl or shale; No. 2, red sandstone, used for building; No. 3, conglomerate; and No. 4, grey paving-stone, and tile-stone with green and reddish shale, containing peculiar organic remains. A glance at the section will show that each of the formations 2, 3, 4 is repeated thrice at the surface, twice

with a southerly, and once with a northerly inclination or *dip*; and the beds in No. 1, which are nearly horizontal, are still brought up twice by a slight curvature to the surface, once on each side of A. Beginning at the north-west extremity, the tile-stones and conglomerates, No. 4. and No. 3, are vertical, and they generally form a ridge parallel to the southern skirts of the Grampians. The superior strata, Nos. 2 and 1, become less and less inclined on descending to the valley of Strathmore, where the strata, having a concave bend, are said by geologists to lie in a 'trough' or 'basin.' Through the centre of this valley runs an imaginary line A, called technically a 'synclinal axis,' where the beds, which are tilted in opposite directions, may be supposed to meet. It is most important for the observer to mark the position of such axes, for he will perceive by the diagram that, in travelling from the north to the centre of the basin, he is always passing from older to newer beds; whereas, after crossing the line A, and pursuing his course in the same southerly direction, he is continually leaving the newer, and advancing upon older strata. All the deposits which he had before examined begin then to recur in reversed order, until he arrives at the central axis of the Sidlaw hills, where the strata are seen to form an arch or *saddle*, having an *anti-clinal* axis B in the centre. On passing this axis, and continuing towards the S.E., the formations 4, 3, and 2 are again repeated, in the same relative order of superposition,

Fig. 81.



Section through Forfarshire, from N.W. to S.E., from foot of the Grampians to the sea at Arbroath (volcanic or trap rocks omitted). Length of section twenty miles.

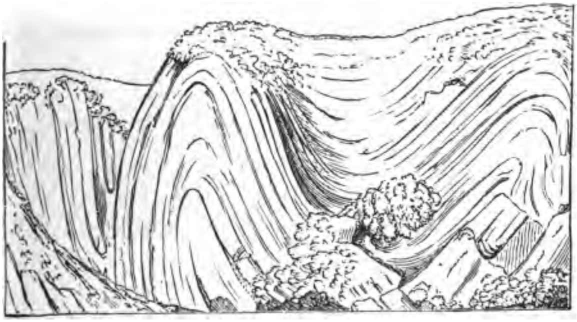
but with a southerly dip. At Whiteness (see diagram) it will be seen that the inclined strata are covered by a newer deposit, *a*,

in horizontal beds. These are composed of red conglomerate and sand, and are newer than any of the groups, 1, 2, 3, 4, before described, and rest *unconformably* upon strata of the sandstone group No. 2.

Strata which are bent into a vertical, or nearly vertical position, and afterwards resume their original horizontality, are said to exhibit a 'uniclinal' or 'monoclinal' fold. A good example of such a monoclinal fold is exhibited by the beds of the Isle of Wight; and the same phenomenon is often presented on a much grander scale in the Western territories of the United States.

An example of curved strata, in which the bends or plications of the rock are sharper and far more numerous within an equal space, has been well described by Sir James Hall.[3] It

Fig. 82.



Curved strata of slate near St. Abb's Head, Berwickshire. (Sir J. Hall.)

occurs near St. Abb's Head, on the east coast of Scotland, where the rocks consist principally of a bluish slate, having frequently a ripple-marked surface. The undulations of the beds reach from the top to the bottom of cliffs from 200 to 300 feet in height, and there are sixteen distinct bendings in the course of about six miles, the curvatures being alternately concave and convex upwards. All these strata were once horizontal.

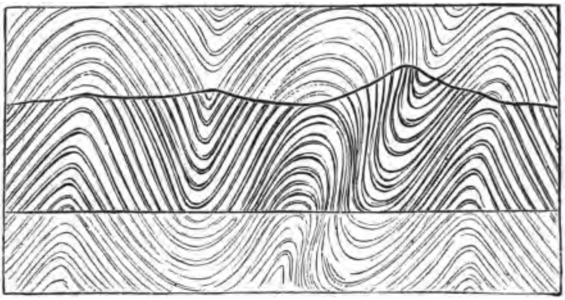
Folding by lateral movement.—An experiment was made by Sir James Hall, with the object of illustrating the manner in which such strata, assuming them to have been originally horizontal, may have been forced into their present position. A set of layers of clay were placed under a weight, and their opposite ends pressed towards each other with such force as to cause them to approach more nearly together. On the removal

[3] 'Edin. Trans.' vol. vii. pl. 3.

of the weight the layers of clay were found to be curved and folded, so as to bear a miniature resemblance to the strata in the cliffs of St. Abb's Head. We must, however, bear in mind that in the natural section or sea-cliff we only see the foldings imperfectly, one part being invisible beneath the sea, and the other, or upper portion, being supposed to have been carried away by *denudation*, or that action of water which will be explained in the next chapter. The dark lines in the accompanying plan (fig. 83) represent what is actually seen of the strata in the line of cliff alluded to; the fainter lines indicate that portion which is concealed beneath the sea-level, as also that which is supposed to have once existed above the present level.

In some cases the flexures found in rocks form regular and sweeping curves; in other cases sharp angular foldings are

Fig. 83.

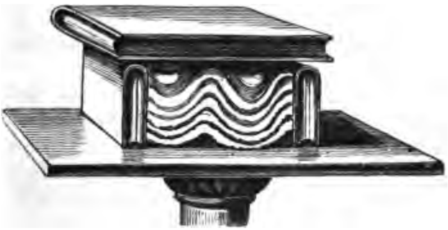


produced, and in other cases the axis plane of the fold becomes inclined, and overfolding with inversion is the result.

We may still more easily illustrate the effects which a lateral thrust must produce on flexible strata, by placing several pieces of differently coloured cloths upon a table, and when they are spread out horizontally, covering them with a book; then applying other books to each end, and forcing them towards each other. The folding of the cloths (see fig. 84) will imitate those of the bent strata; the incumbent book being slightly lifted up, and no longer touching the two volumes on which it rested before, because it is supported by the tops of the anticlinal ridges formed by the curved cloths. In like manner there can be no doubt that the squeezed strata, although laterally condensed and more closely packed, are yet elongated and made to rise upwards in a direction perpendicular to the pressure.

Whether the analogous flexures in stratified rocks have really been due to similar lateral movements is a question which we cannot decide by reference to our own observation. Our inability to explain the nature of the process is, perhaps, not simply owing to the inaccessibility of the subterranean regions where the mechanical force is exerted, but to the extreme slowness of the movement. The changes may sometimes be due to variation in the temperature and chemical constitution of mountain masses of rock, causing them, while still solid, to expand or contract. If such be the case, we have scarcely more reason to expect to witness the operation of the process within the limited periods of our scientific observation than to see the swelling of the roots of a tree, by which, in the course of years, a wall of solid masonry may be lifted up, rent, or thrown down. In both instances the force may be irresistible, but though adequate, it need not be visible to us, provided the time re-

Fig. 84.



quired for its development be very great. The lateral pressure arising from the unequal expansion of rocks by heat may cause one mass lying in the same horizontal plane gradually to occupy a larger space so as to press upon another rock, which, if flexible, may be squeezed into a bent and folded form. It will also appear, when the volcanic and plutonic rocks are described, that some of them, when melted in the interior of the earth's crust, have been injected forcibly into fissures, and after the solidification of such intruded matter, other sets of rents, crossing the first, have been formed and in their turn filled by melted rock. Such repeated injections imply a stretching, and often upheaval, of the whole mass.

We also know, especially by the study of regions liable to earthquakes, that there are causes at work in the interior of the earth capable of producing a sinking in of the ground, sometimes very local, but often extending over a wide area. The continuance of such a downward movement, especially if partial

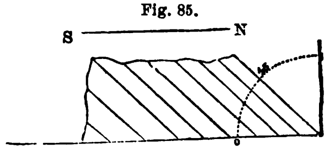
and confined to linear areas, may produce regular folds in the strata.

But the cause of the great flexures and curvatures of strata that are such grand features in mountains, is the same as that which produces elevation and subsidence on the greatest scale, and is that which produced the continents and sea-floors. The force was directed tangentially to the earth's surface, and lateral compression resulted; the original horizontal strata were forced into anticlinal and synclinal curves, and the breadth of area was diminished. The force was the outcome of the energy of heat within the globe. As the internal heat was conducted to the surface through cooling rocks, to be radiated into space, contraction occurred. The contraction was unequal, because rocks contract at different rates in cooling. These irregular contractions produced dragging down of the superficies, and a resolved force was produced, the direction of which was tangential. The phenomena of slaty cleavage, and some metamorphism, hereafter to be considered, are the proofs of the direction of the force and of its effects. The positions assumed by strata in mountain-chains are also evidences of the same forces.

It is in mountain-chains, indeed, that we find the most striking examples of the extreme results of lateral pressure upon stratified rock-masses. The complicated folds have their axes greatly inclined, and the middle limb is frequently dragged out or crushed, so that the fold is converted into a fault, as was shown by H. D. Rogers. Very exaggerated examples of such broken folds are called by some authors thrusts; and examples of them have been described in the Appalachians, the Scottish Highlands, and the Alps. This subject will be more fully considered in connection with the study of the metamorphic rocks.

Dip and strike.—In describing the manner in which strata depart from their original horizontality, the technical terms such as 'dip' and 'strike' are used by geologists. These we shall now proceed to explain. If a stratum or bed of rock, instead of being quite level, be inclined to the horizon,

Fig. 85.



it is said to *dip*; the point of the compass to which it is inclined is called the *direction of dip*, and the degree of deviation from a horizontal plane is called *the amount of dip*, or *the angle of dip*. Thus, in the annexed diagram (fig. 85), a series of strata are inclined, and they dip to the north at an angle of forty-five

degrees. The *strike*, or *line of bearing*, is the prolongation or extension of the strata in a direction *at right angles* to the dip. Thus, in the above instance of strata dipping to the north, their strike must necessarily be east and west. We have borrowed the word from the German geologists, *streichen* signifying to extend, to have a certain direction. A stratum which is horizontal, or quite level in all directions, has neither dip nor strike.

It is always important for the geologist, who is endeavouring to comprehend the structure of a country, to learn how the beds dip in every part of the district; but it requires some practice to avoid being occasionally deceived, both as to the direction of dip and the amount of it.

If the upper surface of a hard stony stratum be uncovered, whether artificially as in a quarry, or by the waves at the foot of

Fig. 86.

Apparent horizontality of inclined strata.

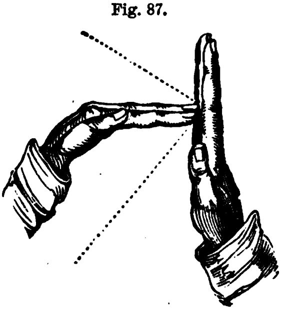
a cliff, it is easy to determine towards what point of the compass the slope is steepest, or in what direction water would flow, if poured upon it. This is the true dip. But the edges of highly inclined strata may give rise to perfectly horizontal lines in the face of a vertical cliff, if the observer see the strata in the line of their strike, the dip being inwards from the face of the cliff. If, however, we come to a break in the cliff, which exhibits a section exactly at right angles to the line of the strike, we are then able to ascertain the true dip. In the drawing above (fig. 86), we may suppose a headland, one side of which faces to the north, where the beds would appear perfectly horizontal to a person in the boat; while on the other side, facing the west, the true dip would be seen by the person on shore to be at an angle of 40°. If, therefore, our observations are confined to a vertical precipice facing in one direction, we must endeavour to find a ledge or portion of the plane of one

of the beds projecting beyond the others, in order to ascertain the true dip.

The *true dip* is always at right angles to the strike; any inclination of strata measured on a plane which is not at right angles to the strike we call *apparent dip*. Many of the inclinations of strata seen in sea-cliffs, quarries, &c., are evidently apparent and not true dips. From one or more apparent dips, the relation of which to the strike is known, it is always possible to calculate the true dip of a bed. Dips (apparent and true) are measured by means of instruments called clinometers, in which the vertical is given by a plumb-line or the horizontal plane by a spirit level.

If not provided with a clinometer—a most useful instrument when it is of consequence to determine the inclination of the strata with precision—the observer may measure the angle within a few degrees, by standing exactly opposite to a cliff where the true dip is exhibited, holding the hands immediately before the eyes, and placing the fingers of one in a perpendicular and of the other in a horizontal position, as in fig. 87. It is thus easy to discover whether the lines of the inclined beds bisect the angle of 90°, formed by the meeting of the hands, so as to give an angle of 45°, or whether it would divide the space into two equal or unequal portions. You have only to change hands to get the dip indicated by the lower dotted line on the upper side of the horizontal hand.

Fig. 87.

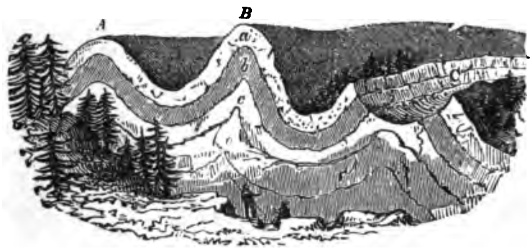


It has been already seen, p. 80, in describing the curved strata on the east coast of Scotland, in Forfarshire and Berwickshire, that a series of concave and convex bendings are occasionally repeated several times. These usually form part of a series of parallel waves of strata, which are prolonged in the same direction, throughout a considerable extent of country. Thus, for example, in the Swiss Jura, that lofty chain of mountains has been proved to consist of many parallel ridges, with intervening longitudinal valleys, as in fig. 88, the ridges being formed by curved fossiliferous strata, the nature and dip of which are occasionally displayed in deep transverse gorges, called 'cluses,' caused by fractures at right angles to the direction of the chain. Now let us suppose these ridges and parallel valleys to run north and south, we should then say that the

strike of the beds is north and south, and the *dip* east and west. Lines drawn along the summits of the ridges A, B, would be anticlinal axes, and one following the bottom of the adjoining valleys a synclinal axis.

It frequently happens that while the inclination of a series of strata is, on the whole, in one particular direction, we find

Fig. 88.

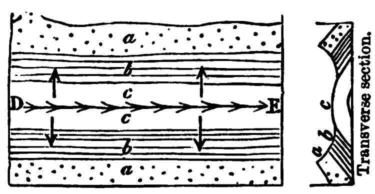


Section illustrating the structure of the Swiss Jura.

many irregularities in the amount of dip at certain points, and that occasionally the dip may be reversed. The careful study of such strata shows that, while having a general slope in one direction, the beds really lie in a series of very flat folds. The prevailing inclination of the beds we speak of as the *general dip*; minor exhibitions of slope in the beds we call *local dip*.

Outcrop of strata.—It will be observed that some of these ridges, A, B (fig. 88), are unbroken on the summit, whereas one of them, C, has had its upper portion carried away by denudation, so that the ridges of the beds in the formations *a*, *b*, *c*, come out to the day, or, as the miners say, *crop out*, on the sides of a valley. The ground plan of such a denuded ridge as C, as given in a geological map, may be expressed by the diagram fig. 89, and the cross section of the same by fig. 90. The line D E, fig. 89, is the axis of the anticlinal, on each side of which the dip is in opposite directions, as expressed by the arrows. The emergence of strata at the surface is called by miners their *outcrop* or *basset*.

Fig. 89. Fig. 90.

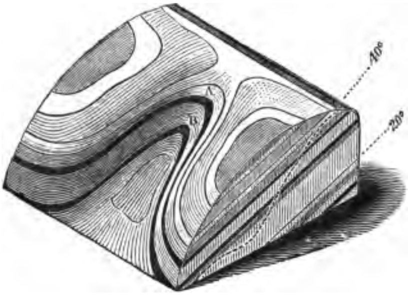


Ground plan of the denuded ridge C, fig. 88.

If, instead of being folded into parallel ridges, the beds form

a boss or dome-shaped protuberance, and if we suppose the summit of the dome cut off by a horizontal plane, the ground plan would exhibit the edges of the strata forming a succession of circles, or ellipses, round a common centre. These circles

Fig. 91.

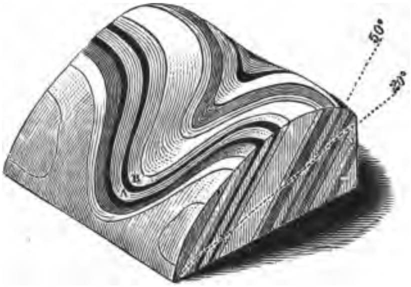


Slope of valley 40°, dip of strata 20°.

are the lines of strike, and the dip being always at right angles is inclined in the course of the circuit to every point of the compass, constituting what is termed a quaquaversal dip—that is, turning every way.

There are endless variations in the figures described by the basset-edges or outcrops of the strata, according to the different inclination of the beds, and the mode in which they happen to

Fig. 92.



Slope of valley 20°, dip of strata 50°.

have been denuded. One of the simplest rules, with which every geologist should be acquainted, relates to the V-like form of the beds as they crop out in an ordinary valley. First, if the strata be horizontal, the V-like form will be also on a level, and the

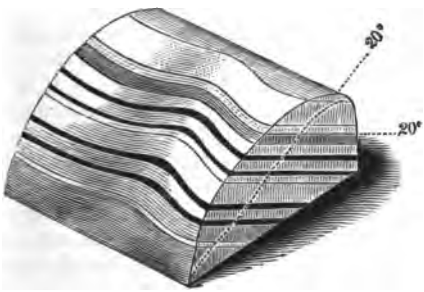
newest strata will appear at the greatest heights on the sides of the valley.

Secondly, if the beds be inclined and intersected by a valley sloping in the same direction, and the dip of the beds be less steep than the slope of the valley, then the V's, as they are often termed by the miners, will point upwards (see fig. 91), those formed by the newer beds appearing in a superior position, and extending highest up the valley, as A is seen above B.

Thirdly, if the dip of the beds be steeper than the slope of the valley, then the V's will point downwards (see fig. 92), and those formed of the older beds will now appear uppermost, as B appears above A.

Fourthly, in every case where the strata dip in a contrary direction to the slope of the valley, whatever be the angle of

Fig. 93.



Slope of valley 20°, dip of strata 20°, in opposite directions.

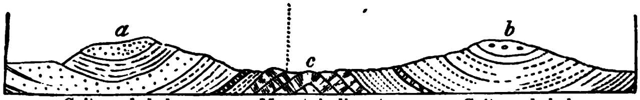
inclination, the newer beds will appear the highest, as in the first and second cases. This is shown by the drawing (fig. 93), which exhibits strata rising at an angle of 20°, and crossed by a valley, which declines in an opposite direction at 20°.

These rules may often be of great practical utility; for the different degrees of dip occurring in the two cases represented in figs. 91 and 92 may occasionally be encountered in following the same line of flexure at points a few miles distant from each other. A miner unacquainted with the rule, who had first explored the valley (fig. 91), may have sunk a vertical shaft below the coal seam A, until he reached the inferior bed B. He might then pass to the valley (fig. 92), and discovering there also the outcrop of two coal seams, might begin his workings in the uppermost in the expectation of coming down to the other bed A, which would be observed cropping out lower down the

valley. But a glance at the section will demonstrate the futility of such hopes.[3]

Synclinal strata forming ridges.—Although in some cases an anticlinal axis forms a ridge, and a synclinal axis a valley, as in A, B, fig. 88, p. 87, yet this can by no means be laid down as a general rule, as the beds very often slope inwards from either side of a mountain, as at *a*, *b*, fig. 94, while in the intervening valley *c* they slope upwards, forming an arch.

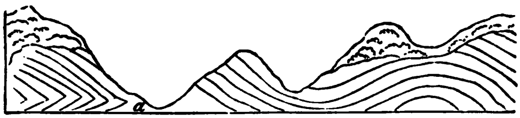
Fig. 94.



Section of carboniferous rocks of Lancashire. (E. Hull.)

At the western extremity of the Pyrenees, great curvatures of the strata are seen in the sea-cliffs, where the rocks consist of marl, grit, and chert. At certain points, as at *a*, fig. 95, some of the bendings of the flinty chert are so sharp that specimens might be broken off, well fitted to serve as ridge-tiles on the roof of a house. Although this chert could not have been brittle as now, when first folded into this shape, it presents, nevertheless, here and there at the points of greatest flexure small cracks, which show that it was solid, and not wholly incapable of breaking, at the period of its displacement. The numerous rents alluded to are not empty, but filled with chalcedony and quartz.

Fig. 95.



Strata of chert, grit, and marl near St. Jean de Luz.

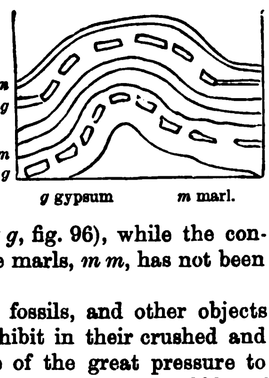
It would be natural to expect the fracture of solid rocks to take place chiefly where the bending of the strata has been sharpest; the entire absence, however, of such cracks at points where the

[3] Sir C. Lyell was indebted to the late T. Sopwith, Esq., for the models which he had copied in the above diagrams; but the beginner may find it by no means easy to understand such copies, although, if he were to examine and handle the originals, turning them about in different ways, he would at once comprehend their meaning as well as the import of others far more complicated, which the same engineer has constructed to illustrate *faults*.

strain must have been greatest, as at *a*, fig. 95, is often very remarkable and not always easy of explanation. We must imagine that many strata of limestone, chert, and other rocks which are now brittle, were pliant when bent into their present position.

It must be remembered that large masses of matter behave very differently from small fragments when force is applied to them. Ice, sealing-wax, and glass are brittle substances, but long rods of these substances are capable of being bent and twisted without breaking. In many cases, too, such substances behave very differently when a force is slowly applied and when it is suddenly brought into action, and when changes of temperature are taking place in a mass it yields much more easily than when maintained at a uniform temperature. The great rock-masses of the earth's crust are of enormous dimensions, they have been subjected to extraordinary variations in temperature, and the forces which have operated on them have acted with extreme slowness.

Fig. 96.



g gypsum *m* marl.

Between Santa Caterina and Castrogiovanni, in Sicily, bent and undulating gypseous marls occur, with here and there thin beds of solid gypsum interstratified. Sometimes these solid layers have been broken into detached fragments, still preserving their sharp edges (*g g*, fig. 96), while the continuity of the more pliable and ductile marls, *m m*, has not been interrupted.

We sometimes find that pebbles, fossils, and other objects included in bent and folded strata exhibit in their crushed and dislocated appearances clear evidence of the great pressure to which the rocks have been subjected. In some cases pebbles of limestone, and even of quartzite, have been thrust against one another with such irresistible force as to cause mutual impressions to be produced upon them; these are called impressed pebbles by geologists. Slickensides are grooved or polished surfaces of rock produced by the grinding of one part of the rock against another during the movements which have taken place.

We have already explained (fig. 94) that stratified rocks have their strata usually bent into parallel folds forming anticlinal and synclinal curves, a group of several of these folds having often been subjected to a common movement, and having acquired a uniform strike or direction. In some disturbed regions

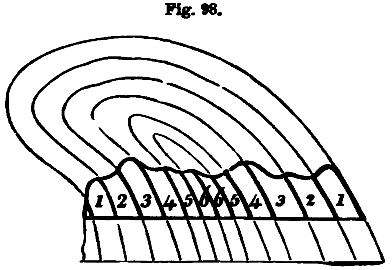
these folds have been doubled back upon themselves in such a manner that it is often difficult for an experienced geologist to determine the relative age of the beds correctly by superposition. Thus, if we meet with the strata seen in the section, fig. 97, we should naturally suppose that there were twelve distinct beds, or sets of beds, No. 1, the uppermost, being the newest, and No. 12 the oldest of the series. But this section may perhaps exhibit merely six beds, which have been folded in the manner seen in fig. 98, so that each of them is repeated, the position of one half being reversed, and part of No. 1, originally the uppermost, having now become the lowest of the series. The upper part of the curves seen in this diagram, fig. 98, and expressed in fainter lines, has been removed by denudation.

Fig. 97.

The phenomena of folding, inversion, and reversal of strata are seen on a magnificent scale in certain regions in Switzerland, in precipices often more than 2,000 feet in perpendicular height, and there are flexures not inferior in dimensions in the Pyrenees.

Ordinary inversion of strata is well seen near Milford, and is explained in the diagram, fig. 99. On passing from N to S the topmost strata, 3, are lower than 2 and 1.

Fig. 98.



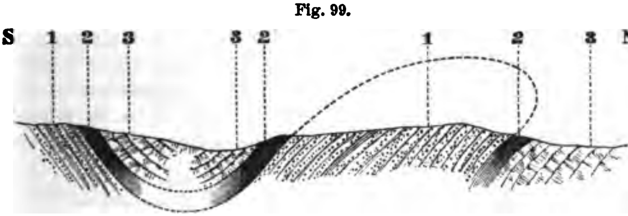
The folding is on such a grand scale and has been so sharp in the Alps that old metamorphic rocks, whose place is below the sedimentary strata, have become included in the folds and exposed by denudation. The old rocks then appear newer than some of the younger strata. In the Mont-Blanc range the lateral crush has been sufficient to cause the sedimentary strata to dip under the old crystalline schists, as will be explained when treating of metamorphic rocks.

Fractures of the strata and faults.—When the force to which a rock-mass has been subjected has resulted in the fracture and displacement of its two portions, we have the phenomenon known to geologists as a *fault*. Numerous rents may often be seen in rocks which appear to have been simply broken, the fractured parts still remaining in contact; but we

often find a fissure, several inches or yards wide, intervening between the disunited portions. These fissures are sometimes filled with fine earth and sand, or with angular fragments of stone, evidently derived from the crushing of the contiguous rocks.

The face of each wall of the fissure is often beautifully polished, as if glazed, striated, or scored with parallel furrows and ridges, such as would be produced by the continued rubbing together of surfaces of unequal hardness. These are the polished surfaces already referred to as 'slickensides.' It is supposed that the lines of the striæ indicate the direction in which the rocks were moved. During one of the minor earthquakes in Chili, in 1840, the brick walls of a building were rent vertically in several places, and made to vibrate for several minutes during each shock, after which they remained uninjured, and without any opening, although the line of each crack was still visible. When

Fig. 99.



Inverted beds near Milford Haven. (After Green.)

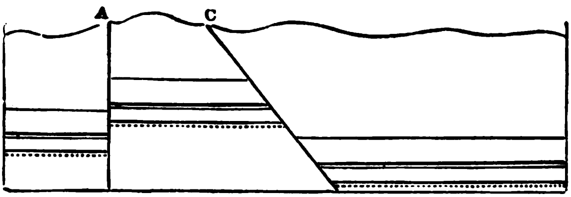
3. Top. Carboniferous limestone.
2. Carboniferous shale.
1. Bottom. Old red sandstone.

all movement had ceased, there were seen on the floor of the house, at the bottom of each rent, small heaps of fine brick-dust, evidently produced by trituration.

It is not uncommon to find the mass of rock, on one side of a fissure, thrown up above or down below the mass with which it was once in contact on the other side. This mode of displacement is called a fault, shift, slip, or throw. Playfair, in describing a fault, remarks: 'The miner is often perplexed, in his subterraneous journey, by a derangement in the strata, which changes at once all those lines and bearings which had hitherto directed his course. When his mine reaches a certain plane, which is sometimes perpendicular, as in A B, fig. 100, sometimes oblique to the horizon (as in C D, ibid.), he finds the beds of rock broken asunder, those on the one side of the plane having changed their place, by sliding in a particular direction along the face of the others. In this motion they have sometimes

preserved their parallelism, as in fig. 100, so that the strata on each side of the faults A B, C D, continue parallel to one another; in other cases, the strata on each side are inclined, as in *a*, *b*, *c*, *d* (fig. 103), though their identity is still to be recognised by their possessing the same thickness and the same internal characters.

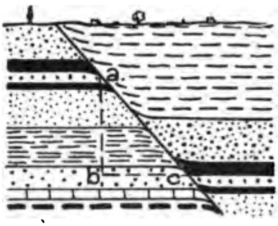
Fig. 100.



Faults. A B vertical, C D hading towards the downthrow.

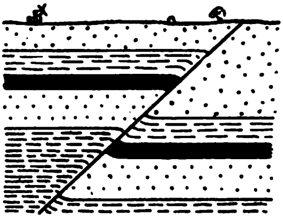
Faults are sometimes vertical, as at A B, fig. 100, but usually they are inclined (C D). The inclination of a fault from the vertical is called its hade. Ordinary faults are those in which the 'hade' is towards the downthrow side of the fault (see fig. 101). Reversed faults are those in which the hade is in the opposite direction (see fig. 102). In the case of an ordinary fault a pit may

Fig. 101.



Ordinary fault. *a b* is the throw or amount of vertical displacement.

Fig. 102.



Reversed fault.

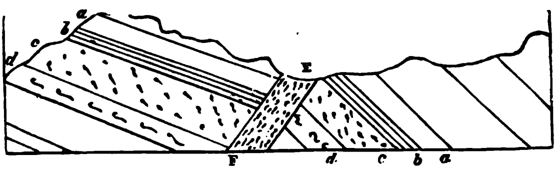
In both cases the bending near the fracture indicates the direction in which the dislocated portion must be sought for.

be sunk so as to avoid the faulted bed altogether; while in the case of a reversed fault a boring or pit may pass through the same bed twice. As seen from these sketches, the strata on the upthrow side of a fault are often bent towards the downthrow, and the opposite is the case on the downthrow side. Lateral displacement of strata occurs in relation to the departure of the fault from the vertical. Usually, the ends of strata close to a

fault are more or less bent: those which have dropped down are bent up against the line of fault, and those which have been pushed up have their edges forced downwards (see figs. 101, 102).

In Coalbrook Dale, deposits of sandstone, shale, and coal, several thousand feet thick and occupying an area of many miles, have been shivered into fragments, and the broken remnants have been placed in very discordant positions, often at levels differing several hundred feet from each other. The sides of the faults, when perpendicular, are commonly several yards apart, and are sometimes as much as 50 yards asunder, the interval being filled with broken *débris* of the strata (fault-rock). In following the course of the same fault it is sometimes found to produce in different places very unequal changes of level, the amount of shift being in one place 300 and in another 700 feet; this may arise from the union of two or more faults. In other cases, the disjointed strata may in certain districts have been subjected to renewed movements, which they have not suffered elsewhere.

Fig. 103.



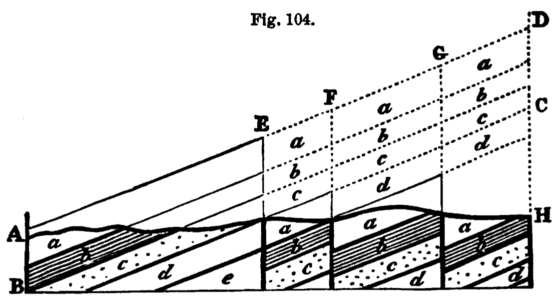
E F, fault or fissure filled with crushed material (fault-rock) on each side of which the shifted strata are not parallel.

We may occasionally see exact counterparts of these slips, on a small scale, in pits of loose sand and gravel, many of which have doubtless been caused by the drying and shrinking of argillaceous and other beds, slight subsidences having taken place from failure of support. Sometimes, however, even these small slips may have been produced by the subterranean movements which are occasionally accompanied by earthquakes; for land has been moved, and its level, relatively to the sea, considerably altered, since much of the alluvial sand and gravel now covering the surface of continents was deposited.

A remarkable instance of the occurrence of the changes just alluded to, in modern times, was observed in New Zealand during the earthquake of January 1855. In the course of the subterranean disturbances a fracture in the strata was produced, extending for a distance of 90 miles. On one side of this fissure, the land was elevated in places as much as 9 feet, so as to form an inland cliff of that height, but on the other side the strata

were unaffected. At the same time, a large district in the North Island, in the neighbourhood of Wellington, was upraised, while on the opposite side of Cook's Strait a subsidence of 5 feet took place, so that ships were obliged to go three miles higher up the river Wairau to obtain a supply of fresh water. A still more remarkable example of movements of the nature of a fault being observed in connection with an earthquake was that which has been described by Dr. B. Kôto as occurring in Japan in 1891. In this case a great rent was produced which could be traced for more than 50 miles, and the surface of the ground was displaced on opposite sides of the fracture, in some cases to the extent of 20 feet. In the roads which traversed the country, moreover, lateral shifting could be seen to have taken place on opposite sides of the fissure, exactly like that which is rendered manifest when faulted beds are accurately mapped.

Fig. 104.



Apparent alternations of strata caused by vertical faults.

We have already stated (p. 92) that a geologist must be on his guard, in a region of disturbed strata, against inferring repeated alternations of rocks, when, in fact, the same strata, once continuous, have been bent round so as to recur in the same section, and with the same dip. A similar mistake has often been occasioned by a series of faults.

If, for example, the dark line A H (fig. 104) represents the surface of a country on which the strata *a b c* frequently crop out, an observer, who is proceeding from H to A, might at first imagine that at every step he was approaching new strata, whereas the repetition of the same beds has been caused by vertical faults, or downthrows. Thus, suppose the original mass, A, B, C, D, to have been a set of uniformly inclined strata, and that the different masses under E F, F G, and G D, sank down successively, so as to leave vacant the spaces marked in the diagram by dotted lines, and to occupy those marked by

the continuous lines, then let denudation take place along the line A H, so that the protruding masses indicated by the fainter lines are swept away—a miner who has not discovered the faults, finding the mass *a*, which we will suppose to be a bed of coal four times repeated, might hope to find four beds, workable to an indefinite depth, but first on arriving at the fault G he is stopped suddenly in his workings, for he comes partly upon the shale *b*, and partly on the sandstone *c*; the same result awaits him at the fault F, and on reaching E he is again stopped by a wall composed of the rock *d*.

The very different levels at which the separated parts of the same strata are found on the different sides of the fissure, in some faults, are truly astonishing. One of the most celebrated faults in England is called the 'ninety-fathom dike,' in the coal-field of Newcastle. This name has been given to it because the same beds are ninety fathoms (540 feet) lower on the northern than they are on the southern side. The fissure has been filled by a body of sand, now converted into sandstone, which is sometimes very narrow, but in other places more than twenty yards wide.[4] The walls of the fissure are scored by grooves, such as would have been produced if the broken ends of the rock had been rubbed along the plane of the fault.[5] In the Tynedale and Craven faults, in the north of England, the vertical displacement, or 'amount of throw,' as it is technically called, is still greater, and the fracture has extended in a horizontal direction for a distance of thirty miles or more. In the district of Morvern, on the shores of the Sound of Mull, tertiary basalts are faulted against the gneiss of the district; the *throw* of the fault being about 2,000 feet. Sir Andrew Ramsay described a fault in North Wales as having a throw of 12,500 feet, or nearly 2½ miles! Some faults run in the same direction as the dip of the strata; they produce a lateral shift of the beds. Others are along the strike (*strike faults*), and often blot out strata by not allowing them to reach the surface. *Step faults* carry down a stratum, which may be near the surface, by a series of parallel dislocations, so that it becomes deeper and deeper, as it were, along a set of steps; while *trough faults* let down a portion of a stratum, which is brought back nearly to its normal position by dislocation in opposite directions (see fig. 261, p. 235).

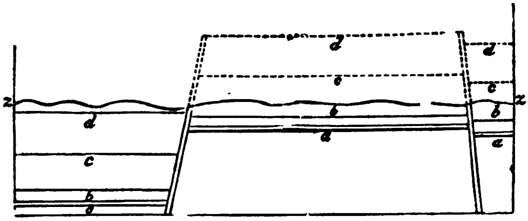
Great faults the result of repeated movements.—It must not, however, be supposed that faults generally consist of single linear rents; there are usually a number of faults springing off

[4] Conybeare and Phillips, Outlines, &c. p. 376.
[5] Phillips, Geology, p. 41.

from the main one, and sometimes a long strip of country seems broken up into fragments by sets of parallel and connecting transverse faults. Oftentimes a great line of fault has been repeated or the movements have been continued through successive periods, so that, newer deposits having covered the old line of displacement, the strata both newer and older have given way along the old line of fracture.

Protruding masses of rock forming precipices or ridges along the lines of great faults may occur; but they have usually been removed by denudation. This is well exemplified in nearly every coal-field which has been extensively worked. It is in such districts that the former relation of the beds which have been shifted is determinable with great accuracy. Thus in the coal-field of Ashby-de-la-Zouch, in Leicestershire (see fig. 105), a fault occurs, on one side of which the coal-beds, *a b c d*, must once have risen to the height of 500 feet above the corresponding

Fig. 105.



Faults and denuded coal strata, Ashby-de-la-Zouch. (Mammatt.)

beds on the other side. But the uplifted strata do not stand up 500 feet above the general surface; on the contrary, the outline of the country, as expressed by the line *z z*, is uniformly undulating without any break, and the mass indicated by the dotted outline must have been denuded off and carried away.

In the Lancashire coal-field the vertical displacement has amounted to thousands of feet, and yet all the superficial inequalities which must have resulted from such movements have been obliterated by subsequent denudation. It appears that there are proofs of there having been two periods of vertical movement in one of the faults—one, for example, before, and another after the Triassic epoch.

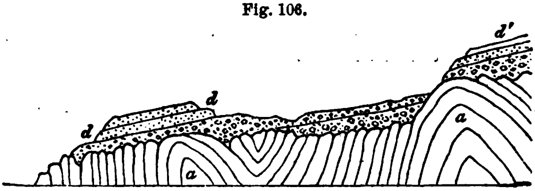
An hypothesis which attributes such a change of position to a succession of movements is far preferable to any theory which assumes each fault to have been accomplished by a single upcast or downthrow of several thousand feet. For we know that there are operations now in progress, at great depths in the

interior of the earth, by which both large and small tracts of ground are made to rise above and sink below their former level, some slowly and insensibly, others suddenly and by starts, a few feet or yards at a time; whereas there are no grounds for believing that, during the last 3,000 years at least, any regions have been either upheaved or depressed, at a single stroke, to the amount of several hundred, much less several thousand feet.

Faulting on a very grand scale accompanied mountain formation, and appears to have occurred as the result of the action of the tangential thrust, or lateral force, which curved and upheaved the mass. The most remarkable of the folds and faults seen in mountain chains are found affecting rock-masses that have suffered metamorphism, and will be discussed in the division of this work which deals with the metamorphic rocks.

Conformable and unconformable stratification.—When strata rest one upon the other horizontally or with the same

Fig. 106.



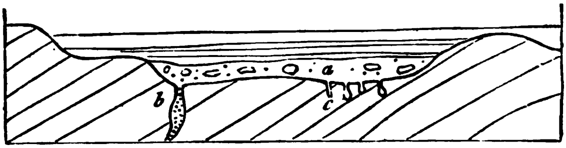
Unconformable junction of old red sandstone and Silurian schist at the Sicarr Point, near St. Abb's Head, Berwickshire.

dip, they are conformable. But strata are said to be unconformable when one series is so placed over another that the planes of the superior repose on the edges of the inferior (see fig. 106). In this case it is evident that a period had elapsed between the production of the two sets of strata, and that, during this interval, the older series had been tilted and disturbed. Afterwards the upper series accumulated, in horizontal strata, upon it. If these superior beds, *d d*, fig. 106, are also inclined, it is plain that the lower strata, *a a*, have been twice displaced—first, before the deposition of the newer beds, *d d*, and a second time when the same strata were upraised out of the sea, and thrown slightly out of the horizontal position.

It often happens that in the interval between the deposition of two sets of unconformable strata, the inferior rock has not only been denuded, but drilled by perforating shells. Thus, for example, at Autreppe and Gusigny, near Mons, beds of an ancient (palæozoic) limestone, highly inclined, and often bent,

are covered with horizontal strata of greenish and whitish marls of the Cretaceous formation (fig. 107). The lowest, and therefore the oldest, bed of the horizontal series is usually the sand and conglomerate, *a*, in which are rounded fragments of stone, from an inch to two feet in diameter. These fragments have often adhering shells attached to them, and have been

Fig. 107.

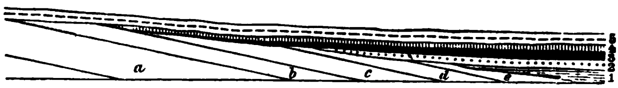


Junction of unconformable strata near Mons, in Belgium.

bored by perforating mollusca. The solid surface of the inferior limestone has also been bored, so as to exhibit cylindrical and pear-shaped cavities, as at *c*, the work of saxicavous mollusca; and many rents, as at *b*, which descend several feet or yards into the limestone, have been filled with sand and shells, similar to those in the stratum *a*.

Overlap of strata.—Strata are said to overlap when an upper bed extends beyond the limits of a lower one. Sediment spread over a region of subsidence has the area of deposit gradually increased, and the newest formed strata will overlap the next below them if these be inclined and their edges denuded. Thus, as shore lines have subsided, shallow-water marine deposits have crept over the land, and as subsidence has progressed, deep-water deposits have been laid down upon these

Fig. 108.



Overlap of strata.

a b c d e, Jurassic rocks. 1. Wealden. 2. Lower greensand. 3. Gault. 4. Upper greensand. 5. Chalk. (From Jukes-Brown, Phys. Geol. p. 388.)

last. Unconformable overlap ('overstep' of some authors) results when one set of strata rest upon others with a different angle of dip. When unconformable overlap is noticed, lapse of time and alterations in the physical geography of the area are inferred to have taken place between the deposition of the last stratum of the lower formation and the first of the upper formation; and this is more obvious when erosion of a lower

stratum is seen to have taken place before the deposition of the upper.

It is usually found that when two series of strata are unconformable or overlap, and thus exhibit a physical break, their fossils differ considerably. This change in fossils is termed a palæontological break, and it may be slight or very nearly absolute, as between the Chalk and the overlying Tertiaries.

Dip-slopes and Escarpments. The action of denudation, or the wearing away of the surface of the land, will be fully discussed in the next chapter; but it will be necessary to consider some of the effects of that action in this place in order to explain some of the appearances presented by the outcrop of strata.

When one stratum is harder than those above and below it, sloping surfaces determined by the dip of the strata are produced by denudation, and these are called *dip-slopes.* The steep slopes formed where such beds are worn away are called escarpments. In fig. 109 the upper Cretaceous strata are represented overlying all the older beds down to the Palæozoic; but the parts indicated by dotted lines have been removed by denudation.

The beds of chalk, *o*, exhibit a good example of a dip-slope on the right and a steep escarpment to the left.

Outliers and Inliers. — The same diagram illustrates the formation by denudation of those isolated patches of a stratum known to geologists as *outliers.* Although the greater part of the beds indicated by the dotted lines have been swept away, portions still remain-

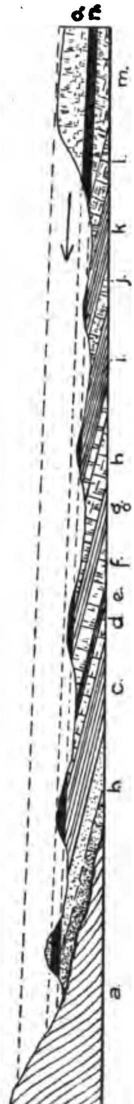


Fig. 109.

a. Palæozoic rocks. *b.* Trias. *c.* Lower Lias. *d.* Middle Lias.
e. Upper Lias. *f.* Inferior Oolite. *g.* Fuller's earth. *h.* Great Oolite.
i. Oxford clay. *j.* Coralline Oolite. *k.* Kimeridge clay. *l.* Portland Oolite.
m. Lower Greensand. *n.* Upper Greensand. *o.* Chalk.

(The beds *n* and *o* are unconformable to and overlap all the others.)

lying beyond the escarpment formed by the mass of the Chalk and Upper Greensand. Thus there have been formed a number of outliers of the Upper Greensand, and on the left of the section is seen an outlier composed of both Upper Greensand and Chalk. On a map these outliers are seen as isolated patches of a stratum surrounded by older beds. Occasionally, when beds have been bent into folds, denudation causes the exposure of portions of an older stratum in the midst of a newer one. Such exposures were called by the older geologists 'outliers by protrusion,' but the officers of the English Geological Survey have introduced the use of the more convenient term *inlier* for masses of strata showing these relations.

It is most important that the student should try to master the problems of solid geometry involved in the bending and fracture of great stratified masses, and the superficial appearances produced by the subsequent planing away of their surfaces by denudation. Great assistance will be obtained by the careful study of Professor Green's 'Physical Geology,' third edition, 1882, chapter xi., and of Professor James Geikie's 'Outlines of Geology,' second edition, 1888, chapter xv. The names applied in different countries to various kinds of flexures and faults are explained in Heim and Margerie's 'Les Dislocations de l'écorce terrestre,' 1888.

CHAPTER IX

DENUDATION AND ITS EFFECTS

Denudation defined—Its amount more than equal to the entire mass of stratified deposits in the earth's crust—Subaërial denudation—Action of the wind—Action of running water—Alluvium defined—Different ages of alluvium—Denuding power of rivers affected by rise or fall of land—Littoral denudation—Inland sea-cliffs—Escarpments—Submarine denudation—Doggerbank—Newfoundland bank—Denuding power of the ocean during emergence of land.

DENUDATION, which has been occasionally referred to in the preceding chapters, consists in the disintegration or breaking up of the earth's surface and the removal of the products by water in motion—whether of rivers or of the waves and currents of the sea—and by wind, and the consequent laying bare of some inferior rock. This operation has exerted an influence on the structure of the earth's crust as universal and important as sedimentary deposition itself; for denudation is the necessary antecedent of the production of all new strata of mechanical origin. The formation of every new deposit by the transport of sediment and pebbles necessarily implies that there has been, somewhere else,

a grinding down of rock into rounded fragments, sand, or mud, equal in quantity to the new stratum. All deposition, therefore —except in the case of a shower of volcanic ashes, the outflow of lava, and the growth of certain organic formations—is the sign of former superficial waste, or of that going on contemporaneously, and to an equal amount, elsewhere. The gain at one point is no more than sufficient to balance the loss at some other.

Disintegration and transport.—From the preceding remarks it will be apparent that denudation results from the joint operation of two distinct agencies, which we may speak of as *disintegration* and *transport*. By the action of rain and frost the hardest and most solid rocks are broken up, and their surfaces covered by débris or 'rubble.' The accumulation of these masses of rubble would, in time, check the work of disintegration by protecting the surfaces of the solid rocks below them from the further action of rain or frost; but now the other agencies of transport come into play, and by the action of streams and sea-waves the loose masses of disintegrated material are swept away, fresh surfaces of the rock being thus exposed to atmospheric waste. The materials produced by disintegration, and carried to new localities by the various agents of transport, accumulate to form new rocks; this constitutes *deposition*. Denudation resulting from disintegration and transport, and deposition acting on materials supplied by denudation, are the two great processes constantly going on upon the earth as the result of the circulation of air and water over and through its solid crust.

When we see a stone building, we know that somewhere, far or near, a quarry has been opened. The courses of stone in the building may be compared to successive strata, the quarry to a ravine or valley which has suffered denudation. As the strata, like the courses of hewn stone, have been laid one upon another gradually, so the excavation both of the valley and quarry has been gradual.

But we occasionally find in a conglomerate large rounded pebbles of an older conglomerate, which had previously been derived from a variety of different rocks. In such instances we are reminded that strata have been formed by the deposition of denuded materials worn from older strata, and have been curved and elevated into hills and mountains. These in their turn have been worn down by the agents of denudation. In such cases it is evident that the same materials have been in very different conditions and positions over and over again during the mutations which have affected the surface of the globe. De-

nudation and re-deposition have persisted ever since the earth's crust has been covered by an atmosphere and has had its rivers and seas.

Denudation may be classed as subaërial and marine, according as it takes place above or below the level of the sea; and the agents which produce it are the sun's heat, frost, the atmosphere, rain, rivers, and the movements of the sea.

Subaërial denudation.—The sun acts on rocks by heating them, and when the component minerals expand and contract unequally, disintegration is the result. In tropical countries the hardest rocks, like granite, are broken up by this unequal expansion and contraction of the minerals which compose them. In the daytime the rock surfaces become intensely heated, in the night they cool rapidly by radiation; and in consequence of the great strains set up in the mass, flakes of rock are violently torn off, the whole surface of the rock-mass seeming to exfoliate. Similar action may be seen taking place on mountain peaks exposed to equally great vicissitudes of heat and cold. The sun also dries clay at the surface, producing cracks in it which enable other agents, like rain and frost, to act. Prolonged cold, especially of frost acting on the water present in rocks, is a great destroyer of the surface down to some depth, and the principal cause is the expansion of the water during the assumption of the crystalline state of ice. The atmosphere acts both chemically and mechanically, and is assisted by the moisture it contains. Weathering of rocks by the carbon dioxide of the air is assisted by the removal of the bicarbonates by rain. The rapidity with which inscriptions on monuments in churchyards become effaced, when compared with similar records placed within the church, has often been pointed out as a striking illustration of the process of disintegration.

Professor Milne and other authors have shown how the sand-blast erodes the Arabian Wadys, scouring and polishing the rocks, and removing the particles ground away from their exposed surfaces; and there are numerous examples of wind-borne and wind-polished rocks on many sea coasts.

'Weathering' is often very conspicuous in crystalline rocks, such as granite and most volcanic rocks, which are composed of several mineral elements. Through the decomposition of the felspar and other minerals most liable to be chemically affected by air and rain, hard rocks like basalt sometimes crumble to pieces, and may be dug with a spade. Some of the most fertile districts in Italy and France owe their riches to the scoriæ and lava that once issued in a molten condition from the craters

of volcanoes, destroying all the vegetation around, but which since then have cooled and crumbled into dust.

In desert regions, where no rain falls, or where, as in parts of the Sahara, the soil is so salt as to be without any covering of vegetation, clouds of dust and sand attest the power of the wind to cause the shifting of the unconsolidated or disintegrated rock.

In examining volcanic countries, one is much struck with the great superficial changes brought about by this power in the course of centuries. The higher peak of Madeira is about 6,050 feet above the sea, and consists of the skeleton of a volcanic cone now 250 feet high, the beds of which once dipped from a centre in all directions at an angle of more than 30°. The summit is formed of a dike of basalt with much olivine, fifteen feet wide, apparently the remains of a column of lava which once rose to the crater. Nearly all the scoriæ of the upper part of the cone have been swept away, those portions only remaining which were hardened by the contact or proximity of the dike. The wind is seen to be continually removing the dust and finer particles from this exposed mass of volcanic materials.

On the highest platform of the Grand Canary, at an elevation of 6,000 feet, there is a cylindrical column of hard lava, from which the softer matter has been carried away; and other similar remnants of the dikes of cones of eruption attest the denuding power of the wind at points where running water could never have exerted any influence. The waste effected by wind, aided by frost and snow, may not be trifling, even in a single winter, and, when multiplied by centuries, may become indefinitely great.

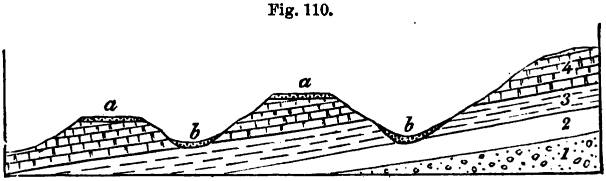
Action of running water.—There are different classes of phenomena which attest in a most striking manner the vast spaces left vacant by the erosive power of water. I may allude, first, to those valleys on both sides of which the same strata are seen following each other in the same order, and having the same mineral composition and fossil contents. We may observe, for example, several formations, as Nos. 1, 2, 3, 4, in the accompanying diagram (fig. 110); No. 1, conglomerate, No. 2, clay, No. 3, grit, and No. 4, limestone, each repeated in a series of hills separated by valleys varying in depth. When we examine the subordinate parts of these four formations, we find, in like manner, distinct beds in each, corresponding, on the opposite sides of the valley, both in composition and order of position. No one can doubt that the strata were originally continuous, and that some cause has swept away the portions which once

connected the whole series. A torrent on the side of a mountain produces similar interruptions; and when we make artificial cuts in lowering roads, we expose, in like manner, corresponding beds on either side. But in nature, these appearances occur in mountains several thousand feet high, and separated by intervals of many miles or leagues in extent.

In general, it is only when rivers are swollen by heavy rain that any considerable quantity of solid matter is removed by their waters. At these times they frequently undermine their banks and precipitate vast masses of earth into the stream; these are rapidly washed away, while in the bed of the river fine gravel and larger fragments of loose stone are swept along, as the transporting power of the current is intensified with each addition to its volume.

But the erosive power of rivers would be comparatively insignificant if it were not aided by other causes, by means of which the hard and compact masses of rock, composing so great a part of the earth's crust, are reduced to fragments capable of

Fig. 110.



a. Older alluvium, or drift. *b*. Modern alluvium.

being easily removed. All the subaërial agents of denudation tend to excavate the ordinary river valley, but cañons, which are deep gorges and ravines, with perpendicular sides, have been excavated by the unassisted power of rivers.

It must be remembered that rivers are mostly very old channels, and that in many instances they have lasted during the epoch of mountain formation which determined their existence, and ever since. Lowering of the surface, the formation of all the features of the hills, and the production of deep river gorges have progressed slowly and variably, but the main drainage has lasted on.

In considering the erosive power of rivers, it must be remembered that the oscillation or meandering of streams from side to side in their flood plains has been and is an important factor in sweeping down gravels and muds towards the sea.

Denuding powers of rivers affected by rise or fall of land.—It has long been a matter of common observation that most rivers are now cutting their channels through alluvial de-

posits of greater depth and extent than could ever have been formed by the present streams. From this fact it has been inferred that rivers in general have grown smaller, or become less liable to be flooded than formerly. It may be true that, in the history of almost every country, the rivers have been both larger and smaller than they are at the present moment. For the rainfall in particular regions varies according to climate and physical geography, and is especially governed by the elevation of the land above the sea, or its distance from it, and other conditions equally fluctuating in the course of time. But the phenomenon alluded to may sometimes be accounted for by oscillations in the level of the land, experienced since the existing valleys originated, even where no marked diminution in the quantity of rain and in the size of the rivers has occurred.

Suppose, for example, part of a continent, comprising within it a large hydrographical basin like that of the Mississippi, to subside several inches or feet in a century. It will rarely happen that the rate of subsidence will be everywhere equal, and in many cases the amount of depression in the interior will regularly exceed that of the region nearer the sea. Whenever this happens, the fall of the waters flowing from the upland country will be diminished, and each tributary stream will have less power to carry its sand and sediment into the main river, and the main river less power to convey its annual burden of transported matter to the sea. All the rivers, therefore, will proceed to fill up their ancient channels partially, and, during frequent inundations, will raise their alluvial plains by new deposits. If, then, the same area of land be again upheaved to its former height, the fall, and consequently the velocity, of every river will begin to augment. Each river then will be less given to overflow its alluvial plain; and its power of carrying earthy matter seaward, and of scouring out and deepening its channel, will be sustained, until, after a lapse of years, a new channel or valley will be found to have been eroded through a fluviatile formation of comparatively modern date. The surface of what was once the river-plain at the period of greatest depression will then remain fringing the valley sides in the form of a terrace apparently flat, but in reality sloping down with the general inclination of the river. Everywhere this terrace will present cliffs of gravel and sand, facing the river. That such a series of movements has actually taken place in the main valley of the Mississippi and in its tributary valleys during oscillations of level has been proved by geological investigations; and the freshwater shells of existing species and bones of land quadrupeds, partly of extinct races, preserved in

the terraces of fluviatile origin, attest the exclusion of the sea, during the whole process of filling up and partial re-excavation.

Escarpments are the abrupt faces of rocks of various kinds which sometimes resemble sea-cliffs, but are often found far inland. They may extend for many miles and bound many valleys, and have more or less precipitous faces. They are due to subaërial denudation, and must be carefully distinguished from cliffs due to marine action.

It was at one time supposed that the steep line of cliff-like slopes seen along the outcrop of the chalk, when we follow the edge of the North or South Downs, was due to marine action; but Sir A. Ramsay and other authors have shown that the physical geography of the district points to the idea of the escarpments having been due to gradual waste since the rocks were exposed to the atmosphere, and to the action of rain and rivers.

Mr. Whitaker has given a good summary of the grounds for ascribing these apparent sea-cliffs to waste in the open air. 1. There is an absence of all signs of ancient sea-beaches or littoral deposits at the base of the escarpment. 2. Great inequality is observed in the level of the base line. 3. The escarpments do not intersect a series of distinct rocks like sea-cliffs, but are always confined to the boundary line of the same formation. 4. There are sometimes different contiguous and parallel escarpments—those, for example, of the greensand and chalk—which are so near each other, and occasionally so similar in altitude, that we cannot imagine any existing archipelago, if converted into dry land, to present a similar outline.

The above theory is by no means inconsistent with the opinion that the limits of the outcrop of the chalk and greensand, which the escarpments now follow, were originally determined by marine denudation. When the south-east of England last emerged from beneath the level of the sea, it was acted upon, no doubt, by the tide, waves, and currents, and the chalk would form, from the first, a mass projecting above the more destructible clay called gault. Still the present escarpments so much resembling sea-cliffs have, no doubt, for reasons above stated, derived their most characteristic features, subsequently to emergence, from subaërial waste by rain and rivers.

The vast results of denudation in past time are exhibited in a most impressive manner in those districts where we see some of the older strata of the earth appearing at the surface, as, for example, in the middle of an anticlinal curve (fig. 83, p. 82), on either side of which rest a long series of succeeding and conformable strata. The newer beds must once have arched over

the whole area, and have been stripped off, before the older strata could have been laid bare.

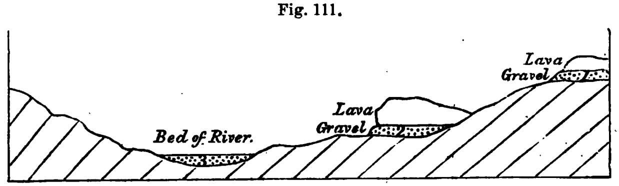
In the 'Memoirs of the Geological Survey of Great Britain' (vol. i.), Sir A. Ramsay has shown that the missing beds, removed from the summit of the Mendips, must have been nearly a mile in thickness; and he has pointed out considerable areas in South Wales and some of the adjacent counties of England, where a series of very ancient or palæozoic strata, not less than 11,000 feet in thickness, has been stripped off. All these materials have of course been transported to new regions, and have entered into the composition of more modern formations. It is clear that such old rocks, mostly formed of mud and sand, and consolidated, were the monuments of denuding operations, which must have taken place at some of the remotest periods of the earth's history yet known to us. For whatever has been given to one area must always have been borrowed from another; a truth which, obvious as it may seem when thus stated, must be repeatedly impressed on the student's mind, because in many doubtful geological speculations, it has been wrongly stated that the crust of the earth has been always growing thicker in consequence of the accumulation, period after period, of sedimentary matter, as if the new strata were not always produced at the expense of pre-existing rocks, stratified or unstratified.

It is well known that deltas are forming at the mouths of some large rivers, and the land is encroaching upon the sea; these deltas are monuments of recent denudation and deposition; and it is obvious that if the mud, sand, and gravel were taken from them and restored to the continents, they would fill up a large part of the ravines and valleys which are due to the excavating and transporting power of torrents and rivers. By duly reflecting on the fact, that all deposits of mechanical origin imply the transportation from some other region, whether contiguous or remote, of an equal amount of solid matter, we perceive that the stony exterior of the planet must always have grown thinner in one place, whenever, by accessions of new strata, it was acquiring thickness in another.

Alluvium.—Between the superficial covering of vegetable mould and the subjacent rock there often intervenes, in many districts, a deposit of loose gravel, sand, and mud, to which, when it occurs in valleys, the name of alluvium has been popularly applied. The term is derived from *alluvio*, an inundation, or *alluo*, to wash, because the pebbles and sand commonly resemble those of a river's bed, or the mud and gravel washed over low lands by a flood.

In the course of those changes in physical geography which may take place during the gradual emergence of the bottom of the sea and its conversion into dry land, any spot may have been either a sunken reef, or a bay, or an estuary, or sea-shore, or the bed of a river. The drainage, moreover, may have been deranged again and again by earthquakes, during which temporary lakes may have been caused by landslips, and partial deluges occasioned by the bursting of the barriers of such lakes. For this reason it would be unreasonable to hope that we should ever be able to account for all the alluvial phenomena of each particular country, seeing that the causes of their origin are so various. And, further, the last operations of water have a tendency to disturb and confound together all pre-existing alluvia. Hence we are always in danger of regarding as the work of a single era, and the effect of one cause, what has in reality been the result of a variety of distinct agents during a long succession of geological epochs. Much useful instruction may therefore be gained from the exploration of a country like Auvergne, where

Fig. 111.



Lavas of Auvergne resting on alluvia of different ages.

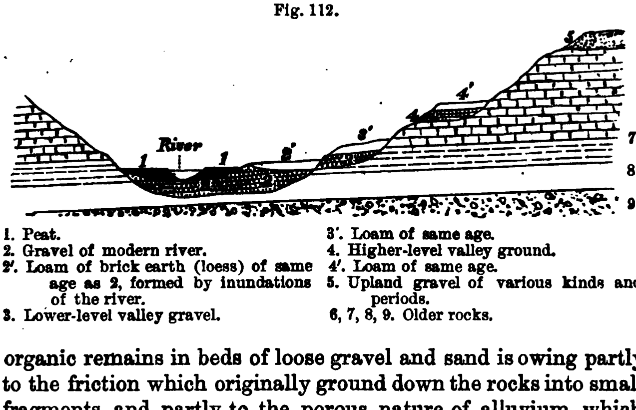
the superficial gravel of very different eras happens to have been preserved and kept separate by sheets of lava, which were poured out, one after the other, at periods when the denudation, and probably the upheaval, of rocks were in progress. That region had already acquired in some degree its present configuration before any volcanoes were in activity, and before any igneous matter was superimposed upon the granitic and fossiliferous formations. The pebbles, therefore, in the older gravels are exclusively constituted of granitic and gneissic rocks; and afterwards, when volcanic vents burst forth into eruption, those earlier alluvia were covered by streams of lava, which protected them from intermixture with gravel of subsequent date. In the course of ages, a new system of valleys was excavated, so that the rivers ran at lower levels than those at which the first alluvia and sheets of lava were formed. When, therefore, fresh eruptions gave rise to new lava, the melted matter was poured out over lower grounds; and the gravel of these plains differed from the first or upland alluvium, by containing in it rounded

fragments of various volcanic rocks, and often fossil bones belonging to species of land animals different from those which had previously flourished in the same country.

The annexed drawing (fig. 111) will explain the different heights at which beds of lava and gravel, each distinct from the other in composition and age, are observed, some on the flat tops of hills 700 or 800 feet high, others on the slope of the same hills, and the newest of all in the channel of the existing river, where there is usually gravel alone, although in some cases a narrow strip of solid lava shares the bottom of the valley with the river.

The proportion of extinct species of quadrupeds is more numerous in the fossil remains of the highest gravel than in that lower down; and in the bed of the river they agree with those of the existing fauna. The usual absence or rarity of

Fig. 112.



1. Peat.
2. Gravel of modern river.
2'. Loam of brick earth (loess) of same age as 2, formed by inundations of the river.
3. Lower-level valley gravel.
3'. Loam of same age.
4. Higher-level valley ground.
4'. Loam of same age.
5. Upland gravel of various kinds and periods.
6, 7, 8, 9. Older rocks.

organic remains in beds of loose gravel and sand is owing partly to the friction which originally ground down the rocks into small fragments, and partly to the porous nature of alluvium, which allows the free percolation through it of rain-water, and promotes the decomposition and removal of fossil remains.

But even in cases where the alluvia produced by successive stages of denudation are not sealed up, as in Auvergne, under beds of lava, we may frequently recognise the evidence of a sequence of deposits in a series of terraces on the sides of river valleys. As shown by Professor Prestwich, the upland or plateau gravels (see fig. 112) must have been spread out before the excavation of the valley, and the higher level and lower level gravels must each have formed the bottom of the valley before it was excavated to its present depth. As in the case of Auvergne, this succession of events is confirmed by the study of the fossils found in these successive alluvia.

Under the name of *diluvium* or drift, the older geologists used to distinguish those masses of loose material which often attain great thicknesses, and are formed of materials that indicate more violent action than that which has accumulated the alluvia of our river valleys. Such deposits were at one time thought to have been produced by the action of violent floods sweeping over the land and carrying blocks of stone of great size and vast quantities of sand and mud from one region to another.

The more careful study of these diluvial deposits or drifts has shown that they must have been accumulated by the action of ice—either as glaciers, icebergs or shore-ice. Ice, as we shall see in a subsequent chapter, is a most important agent of disintegration and transport. Rocks have their surfaces scored, smoothed, and polished by rock-fragments frozen into the bottoms of glaciers, and these fragments are at the same time ground to the finest dust. Glaciers and icebergs transport blocks of the largest size, as well as sand and mud, to great distances; and, by the action of ice, vast masses of material are accumulated both on the land and under the sea, forming what are known as 'glacial' deposits. Most of the deposits formerly classed as 'diluvium' can now be shown to have resulted directly or indirectly from the action of glaciers, icebergs, and shore-ice.

Marine denudation.—The waves of the sea when driven by storms are continually wearing away the coastline, in some cases undermining the cliffs and hollowing out deep caverns. Cliffs are worn back leaving low foreshores, which are planed more or less level by the waves and tides. Part of the action of the waves between high- and low-water mark must be included in subaërial denudation, more especially as the undermining of cliffs by the waves is facilitated by land-springs, and these often lead to the sliding down of great masses of land into the sea. But the destruction wrought by these means would soon come to an end if the force of the waves and the tides did not break up whatever is brought within their reach, and, by sweeping the fragments to deep water, prepare the way for renewed gains upon the land.

Though the denuding power of the waves is confined within the narrow limits between tide-marks, the phenomena of our raised beaches and submerged forests indicate oscillations of level, and as such movements are very gradual, they must have given repeated opportunities to the breakers to denude the land which was again and again exposed to their fury, although it is evident that the submergence was sometimes effected in such a

manner as to allow the trees which border the coast to be quietly covered up by sediment instead of being carried away.

Ground-swell waves are important agents of denudation when they come into shallow water. Scott Russell showed that a single roller of a ground-swell, 20 feet high, falls with the pressure of a ton on every square foot, and Stevenson stated that the force of the breakers of the Atlantic on the sea-coasts of Britain was 611 lbs. per square foot in summer, and 2,086 lbs. in winter. It is stated that ground swell will influence the bottom at 200 fathoms. But Delesse has proved that engineering operations are scarcely disturbed at a greater depth than 16·4 feet in the Mediterranean Sea, and 26·24 feet in the Atlantic. All modern research tends to show that the greater part of the eroding action of the sea is restricted to within a few fathoms of the shore.

The sea removes the products of its own erosion, and most of the results of subaërial denudation. The mud of rivers sinks sooner or later when in contact with the sea, and clays readily sink in salt water; but it appears that deep-sea deposits remote from land are singularly exempt from materials derived from the land. The vast volumes of soluble matters brought down by the rivers into the sea supply the material of the calcareous and siliceous skeletons of a host of marine organisms.

The littoral deposits, as they are termed, are shingle beds and similar accumulations, and they are rarely stationary. Derived from the fall of cliffs, and worn by the rolling of water and by impact with other stones, the fragments become pebbles, while the sand, resulting from this wearing action, is carried off by tide and currents. Finally, the pebbles collect in masses, which resemble many geological formations, and—were they cemented—would be true conglomerates. The fine materials formed by the wearing down of the fragments and pebbles are spread out in layers, which resemble the sandstones of old with rain-prints and ripple-markings.

Submarine denudation.—When we attempt to estimate the amount of submarine denudation, we become sensible of the disadvantage under which we labour from our habitual incapacity of observing the action of marine currents on the bed of the sea. We know that the agitation of the waves, even during storms, diminishes at a rapid rate, so as to become very insignificant at the depth of a few fathoms; but when large bodies of water are transferred by a current, from one part of the ocean to another, they are known to maintain at some depth such a velocity as must enable them to remove the finer, and sometimes even the coarser, materials of the rocks over which they flow.

As the Mississippi when more than 150 feet deep can keep open its channel and even carry down gravel and sand to its delta, the surface velocity being not more than two or three miles an hour, so a gigantic current like the Gulf Stream, equal in volume to many hundred Mississippis, and having in parts a surface velocity of more than three miles, may in moderately deep water act as a propelling and abrading power. But the efficacy of the sea as a denuding agent, geologically considered, is not dependent on the power of currents to preserve at considerable depths a velocity sufficient to remove sand and mud, because, even where the deposition or removal of sediment is not in progress, the depth of water does not remain constant throughout geological time. Every page of the geological record proves to us that the relative levels of land and sea, and the position of the ocean and of continents and islands, have been always varying, and we may feel sure that some portions of the submarine area are now rising and others sinking. The force of tidal and other currents and of the waves during storms was sufficient to prevent the emergence of many lands, even though they were undergoing continual upheaval. This must always have been the case when the reduction of level by the action of marine currents went on faster than its elevation by subterranean forces. It is not an uncommon error to imagine that the waste of sea-cliffs affords the measure of the amount of marine denudation, of which it probably constitutes an insignificant portion.

Dogger-bank.—That great shoal called the Dogger-bank, about sixty miles east of the coast of Northumberland, and occupying an area about as large as Wales, has nowhere a depth of more than ninety feet, and in its shallower parts is less than forty feet under water. It might contribute towards the safety of the navigation of our seas to form an artificial island, and to erect a lighthouse on this bank; but no engineer would be rash enough to attempt it, as he would feel sure that the ocean in the first heavy gale would sweep it away as readily as it does every temporary shoal that accumulates from time to time around a sunken vessel on the same bank.[1]

No observed geographical changes in historical times entitle us to assume that where upheaval may be in progress it proceeds at a rapid rate. Three or four feet rather than as many yards in a century may probably be as much as we can reckon upon in our speculations; and if such be the case, the continuance of the upward movement might easily be counteracted by the denuding force of such currents aided by such waves as during a

[1] 'Principles,' 10th ed. vol. i. p. 569.

gale are known to prevail in the German Ocean. What parts of the bed of the ocean are stationary at present, and what areas may be rising or sinking, is a matter of which we are very ignorant, as the taking of accurate soundings is but of recent date.

Newfoundland-bank.—The great bank of Newfoundland may be compared in size to the whole of England. This part of the bottom of the Atlantic is surrounded on three sides by a rapidly deepening ocean, the bank itself being from twenty to fifty fathoms (or from 120 to 300 feet) under water. We are unable to determine by the comparison of different charts, made at distant periods, whether it is undergoing any change of level, but if it be gradually rising we cannot anticipate on that account that it will become land, because the breakers in an open sea would exercise a prodigious force even on solid rock brought up to within a few yards of the surface. We know, for example, that when a new volcanic island rose in the Mediterranean in 1831, the waves were capable in a few years of reducing it to a sunken bank.

In the same way currents which flow over the Newfoundland-bank a great part of the year at the rate of two miles an hour, and are known to retain a considerable velocity to near the bottom, may carry away all loose sand and mud and make the emergence of the shoal impossible, in spite of the accessions of mud, sand, and boulders derived occasionally from melting icebergs which, coming from the northern glaciers, are frequently stranded on various parts of the bank. They must often leave at the bottom large erratic blocks which the marine currents may be incapable of moving.

'Needles' and 'No Man's Lands' are portions of cliffs left behind when surrounding parts have been worn down by the sea; they indicate the former extension of the land up to and beyond them seawards. They are, as it were, measures of the strata which have been worn away, and which are recognised in the main cliffs of the land.

Inland sea-cliffs.—In countries where hard limestone rocks abound, inland cliffs have often retained the characters which they acquired when they constituted the boundary of land and sea. Thus, in the Morea, no less than three or even four ranges of cliffs are well preserved, rising one above the other at different distances from the actual shore, the summit of the highest and oldest occasionally attaining 1,000 feet in elevation. A consolidated beach with marine shells is usually found at the base of each cliff, and a line of old shore caverns.

But the beginner should be warned not to expect to find evidence of the former sojourn of the sea on all those lands

which we are nevertheless sure have been submerged at periods comparatively modern; for notwithstanding the enduring nature of the marks left by littoral action on some rocks, especially limestones, we can by no means detect sea-beaches and inland cliffs everywhere. On the contrary, they are, upon the whole, extremely partial, and are often entirely wanting in districts composed of argillaceous and sandy formations, which must, nevertheless, have been upheaved at the same time, and by the same intermittent movements, as the adjoining harder rocks.

Equally necessary is it for the student to avoid confounding ordinary escarpments, formed by subaërial denudation, with true sea cliffs, to which they sometimes exhibit a superficial resemblance.

The importance of subaërial denudation in sculpturing the earth's surface was first shown in Mr. Scrope's classical work on the Volcanoes of Central France.' Sir Andrew Ramsay's 'Physical Geology and Geography of Great Britain,' Col. Greenwood's 'Rain and Rivers,' and Sir A. Geikie's 'Scenery of Scotland, viewed in connection with its Physical Geology,' may all be studied with advantage as supplying valuable illustrations of the principles laid down in this chapter. For an admirable summary of the question see Professor Green's 'Physical Geology,' third edition, vol. xiii.

CHAPTER X

JOINT ACTION OF DENUDATION, UPHEAVAL, AND SUBSIDENCE IN REMODELLING THE EARTH'S CRUST

How we obtain an insight, at the surface, of the arrangement of rocks at great depths—Why the height of the successive strata in a given region is so disproportionate to their thickness—Computation of the average annual amount of subaërial denudation—Antagonism of subterranean forces to the levelling power of running water—How far the transfer of sediment from the land to a neighbouring sea-bottom may affect subterranean movements—Supposed permanence of continental and oceanic areas.

How we obtain an insight, at the surface, of the arrangement of rocks at great depths.—The reader has been already informed that in the structure of the earth's crust we often find proofs of the direct superposition of marine to fresh-water strata, and also evidence of the alternation of deep-sea and shallow-water formations. Sedimentary deposits cannot become thick if exposed to concurrent denudation. Darwin has suggested that all deep sediments must have accumulated during subsidence of the area in which they were formed. In order to explain how such a series of rocks could be made to give rise to our present continents and islands, we have to as-

sume not only that there have been alternate upward and downward movements of great vertical extent, but that the upheaval in the areas which we at present inhabit has, in later geological times, sufficiently predominated over subsidence to cause these portions of the earth's crust to be land instead of sea. The sinking down of a delta beneath the sea-level may cause strata of fluviatile or even terrestrial origin, such as peat, to be covered by deposits of deep-sea origin. There is also no limit to the thickness of mud and sand which may accumulate in shallow water, provided that fresh sediment is brought down from the wasting land at a rate corresponding to that of the sinking of the bed of the sea.

The succession of strata here alluded to would be consistent with the occurrence of gradual downward and upward movements of the land and bed of the sea without any disturbance of the horizontality of the several formations. But the arrangement of rocks composing the earth's crust differs materially from that which would result from a mere series of radial vertical movements. Had the internal energies of the globe only produced such movements, and had the stratified rocks been first formed beneath the sea and then raised above it, without any lateral compression, the geologist would never have obtained an insight into the monuments of various ages, some of extremely remote antiquity.

What we have said in Chapter VIII. of dip and strike, of the folding and inversion of strata, of anticlinal and synclinal flexures, and in Chapter IX. of denudation at different periods, whether subaërial or submarine, must be understood before the student can comprehend what may at first seem to him an anomaly, but which it is his business particularly to understand. We allude to the small height above the level of the sea attained by strata, often many miles in thickness, and about the chronological succession of which, in one and the same region, there is no doubt whatever. Had stratified rocks in general remained horizontal, the waves of the sea would have been enabled during oscillations of level to plane off entirely the uppermost beds as they rose or sank during the emergence or submergence of the land. But the occurrence of a series of formations of widely different ages, all remaining horizontal and in conformable stratification, is exceptional, and for this reason the total annihilation of the uppermost strata has rarely taken place. We owe, indeed, to the lateral movements produced by tangential thrust those anticlinal and synclinal curves of the beds already described (fig. 81, p. 80), which, together with denudation, subaërial and submarine, enable us to investigate the

structure of the earth's crust many miles below those points which the miner can reach under other circumstances. It has already been shown in fig. 83, p. 82, how, at St. Abb's Head, a series of strata of indefinite thickness may become vertical, and then denuded, so that the edges of the beds alone shall be exposed to view, the altitude of the upheaved ridges being reduced to a moderate height above the sea-level. The breadth of an exposed edge of a stratum is equivalent to its thickness when the vertical position is assumed. It may be observed that, although the incumbent strata of Old Red Sandstone are nearly horizontal, yet they will in other places be found so folded as to present vertical strata, the edges of which are abruptly cut off, as in 2, 3, 4 on the right-hand side of the diagram, fig. 81, p. 80.

Why the height above sea-level of the successive strata in a given region is so disproportionate to their thickness. We cannot too distinctly bear in mind how dependent we are, for our power of consulting the different pages of those stony records of which the crust of the globe is composed, on the joint action of the internal energies and agents of denudation, the one in disturbing the original position of rocks, and the other in destroying large portions of them. Why, it may be asked, if the ancient bed of the sea has been in many regions uplifted to the height of two or three miles, and sometimes twice that altitude, and if it can be proved that some single formations are of themselves two or three miles thick, do we so often find several important groups resting one upon the other yet attaining only the height of a few hundred feet above the level of the sea?

The American geologists, after carefully studying the Appalachian mountains, have ascertained that the older fossiliferous rocks of that chain (from the Silurian to the Carboniferous inclusive) are not less than 42,000 feet thick, and if they were now superimposed on each other in the order in which they were deposited, they ought to equal in height the Himalayas with the Alps piled upon them. Yet they rarely reach an altitude of 5,000 feet, and their loftiest peaks are no more than 7,000 feet high. The Carboniferous strata forming the highest member of the series, and containing beds of coal, can be shown to be of shallow-water origin, or even sometimes to have originated in swamps in the open air. But what is more surprising, the lowest part of this great Palæozoic series, instead of having been deposited at the bottom of an abyss more than 40,000 feet deep, consists of sediment (the Potsdam sandstone), evidently spread out on the bottom of a shallow sea on which ripple-marked sands were occasionally formed. This vast

thickness of 40,000 feet is *estimated* by measuring the denuded edges of the vertical strata forming the parallel folds into which the originally horizontal Silurian and Carboniferous rocks had been forced, and which 'crop out' at the surface.

A like phenomenon is exhibited in every mountainous country, as, for example, in the European Alps; but we need not go farther than the north of England for its illustration. Thus in Lancashire and central England the thickness of the Carboniferous formation, including the Millstone Grit and Yoredale beds, is computed to be more than 18,000 feet; to this we may add the Mountain Limestone, at least 2,000 feet in thickness, and the overlying Permian and Triassic formations, 3,000 or 4,000 feet thick. How then does it happen that the loftiest hills of Yorkshire and Lancashire, instead of being 24,000 feet high, never rise to 3,000 feet? The denuded edges of the strata, which are in great curves, are measurable, but the bulk of the thickness is below sea-level.

A study of figs. 97 and 98, p. 92, will explain the relation of the thickness of strata to their height above sea-level. It is evident that the denuded edges of very thick masses of strata, which are in great curves, can be measured, although the bulk of the deposit is hidden. Hence masses of stratified rocks may be several miles in thickness, although the elevation attained by them may not be more than a mile above sea-level.

Computation of the average annual amount of subaërial denudation.—Attempts were made by Manfredi in 1736, and afterwards by Playfair in 1802, to calculate the time which it would require to enable the rivers to deliver over the whole of the land into the basin of the ocean. The data were at first too imperfect and vague to allow them even to approximate to safe conclusions. But in our own time similar investigations have been renewed with more prospect of success, the amount brought down by many large rivers to the sea having been more accurately ascertained. Mr. Alfred Tylor, in 1850, inferred that the quantity of detritus now being distributed over the sea-bottom would, at the end of 10,000 years, cause an elevation of the sea-level to the extent of at least three inches. Subsequently Mr. Croll in 1867, and again, with more exactness, in 1868, deduced from the latest measurement of the sediment transported by European and American rivers, the rate of subaërial denudation to which the surface of large continents is exposed, taking especially the hydrographical basin of the Mississippi as affording the best available measure of the average waste of the land. The conclusion arrived at in his able memoir was that the whole terrestrial surface is denuded at the rate of one foot in 6,000

years, and this opinion was enforced by Sir A. Geikie, who published a valuable essay on the subject in 1868.

The student, by referring to the 'Principles of Geology,' may see that Messrs. Humphreys and Abbot, during their survey of the Mississippi, attempted to make accurate measurements of the proportion of sediment carried down annually to the sea by that river, including not only the mud held in suspension, but also the sand and gravel forced along the bottom.

It is evident that when we know the dimensions of the area which is drained, and the annual quantity of earthy matter taken from it and borne into the sea, we can affirm how much on an average has been removed from the general surface in one year; and there seems no danger of our overrating the mean rate of waste by selecting the Mississippi as our example, for that river drains a country equal to more than half the continent of Europe, extends through twenty degrees of latitude, and therefore through regions enjoying a great variety of climate, and some of its tributaries descend from mountains of great height. The Mississippi is also more likely to afford us a fair test of ordinary denudation, because, unlike the St. Lawrence and its tributaries, there are no great lakes in which the fluviatile sediment is thrown down and arrested on its way to the sea. In striking a general average we have to remember that there are large deserts in which there is scarcely any rainfall, and tracts which are as rainless as parts of Peru, and these must not be neglected as counterbalancing others, in the tropics, where the quantity of rain is in excess.

From the careful observations of Messrs. Humphreys and Abbot it is found that the quantity of materials carried down to the sea every year, in suspension and in solution, would, if spread out over the vast area drained by the Mississippi and consolidated into rock, raise that basin by $\frac{1}{6000}$ part of a foot. In other words, the whole Mississippi basin is being lowered by the action of denudation at the rate of one foot in 6,000 years. Small as this rate may seem to be, a little consideration will show what stupendous effects may be produced in long periods of time. The average height of the North American continent is (according to the most recent researches) 2,030 feet. It follows then that if the other rivers of North America are carrying on the work of denudation at the same rate as the Mississippi, the whole North American continent would be swept away and its materials deposited in the ocean in a period of 12,000,000 years.

The results of these calculations are only trustworthy if it is true that the rainfall has not greatly increased or diminished, and that the climate has remained approximately the same.

There can be little doubt that many rivers perform the work of denudation at a much quicker rate than the Mississippi. It has been estimated, in the case of the Ganges, that the quantity of mud carried down to the Bay of Bengal, during four months of wet season of each year, is so great that it would require a fleet of eighty 'Indiamen,' each of 1,400 tons, to set sail every hour of every day during the whole of those four months in order to carry the same amount of material as is done by this river.

The estimates made in the case of some other rivers are as follows:—To reduce the height of the river-basin by one foot would require the following periods in the case of the several rivers: Danube, 6,846 years; Nith, 4,723 years; Yang-tse-kiang, 2,700 years; Ganges, 2,358 years; Elbe, 1,600 years; Rhone, 1,528 years; Hoang Ho, 1,464 years; Po, 729 years.

A rate of 3,000 years for the removal of one foot thickness from the surface in the case of the whole of the rivers of the globe would probably be a very fair average; and, as the mean height of all the land-masses of the globe is about 2,300 feet, it would require about 7,000,000 years, at the present rate of subaërial denudation, to carry away their materials and deposit them beneath the ocean.

Action of hypogene forces in compensating those of subaërial denudation.—In all these estimates it is assumed that the entire quantity of land above the sea-level remains on an average undiminished in spite of annual waste. Were it otherwise, the subaërial denudation would be continually lessened by the diminution of the height and dimensions of the land exposed to waste. It was stated in 1830, in the 'Principles of Geology,' that running water and volcanic action are two antagonistic forces; the one labouring continually to reduce the whole of the land to the level of the sea, the other to restore and maintain the inequalities of the crust on which the very existence of islands and continents depends. We must always bear in mind that it is not simply by upheaval that subterranean movements can counteract the levelling force of running water. For, whereas the transportation of sediment from the land to the ocean or the upheaval of its bed would raise the general sea-level, the subsidence of the sea-bottom by increasing its capacity would check this rise and prevent the submergence of the land.

The average height and area of the land-masses can only be preserved if the increase occasioned by elevation in one part *exceeds* the loss by subsidence elsewhere; the amount removed by denudation from the whole surface of the land is the measure of this excess of elevation over subsidence. It is only by considering the joint action of all the causes that determine the level

of the sea and the height of the land that we can form some idea of the relation of these destroying and renovating energies.

Unless we assume that there is, in volcanic districts, more subsidence than upheaval, we must suppose the volume of the land-masses to be always increasing, by that quantity of volcanic matter which is annually poured out in the shape of lava or ashes, and accumulated on the land, and which is derived from the interior of the earth. The abstraction of this matter causes, no doubt, in some instances, subsidence. Moreover it is possible that the globe has become smaller from contraction during secular cooling.

Hypogene action.—The action of energies within the earth in counterbalancing denudation by producing great curvings of the crust in past times is not a mere matter of conjecture. The student will see in a future chapter that we have proofs of Carboniferous forests hundreds of miles in extent which grew on the lowlands or deltas near the sea, and which subsided and gave place to other forests, until in some regions fluviatile and shallow-water strata with occasional seams of coal were piled one over the other, till they attained a thickness of many thousand feet. These have often been preserved owing to their being forced into synclinal curves and removed out of the range of denudation.

It will be also seen in another chapter that we have evidence of a rich terrestrial flora, the Devonian, even more ancient than the Carboniferous; while, on the other hand, the later Triassic, Oolitic, Cretaceous, and successive Tertiary periods have all supplied us with fossil plants, insects, or terrestrial mammalia; showing that, in spite of great oscillations of level and continued changes in the position of land and sea, the internal energies have maintained a due proportion of dry land. We may appeal also to freshwater formations, such as the Purbeck and Wealden, to prove that in the Oolitic and Neocomian eras there were rivers draining ancient lands in Europe in times when we know that other spaces, now above water, were submerged.

How far the transfer of sediment from the land to a neighbouring sea-bottom may affect subterranean movements.—It has been suggested that the stripping off by denudation of dense masses from one part of a continent and the delivery of the same into the bed of the ocean must have a decided effect in causing changes of temperature in the earth's crust below, or, in other words, in causing the subterranean isothermals to shift their position. If this be so, one part of the crust may be made to rise, and another to sink, by the expansion and contraction of the rocks, of which the temperature is altered.

Persistence and mutability of continental and oceanic areas.—If the thickness of more than 40,000 feet of sedimentary strata, before alluded to, in the Appalachians, proves a preponderance of downward movements of the sea-floor in Palæozoic times in a district now forming the eastern border of North America, it also proves, as before hinted, the continued existence and waste of some neighbouring continent, probably formed of Laurentian rocks, and situated where the Atlantic now prevails. Such an hypothesis would be in perfect harmony with the conclusions forced upon us by the study of the present configuration of our continents, the relation of their height to the depth of the oceanic basins, also to the considerable elevation and extent sometimes reached by drift containing shells of recent species; and still more by the fact of sedimentary strata, several thousand feet thick, as those of central Sicily, or such as flank the Alps and Apennines, containing fossil mollusca sometimes almost wholly identical with species still living.

Movements of 1,000 feet or more would turn much land into sea, and sea into land, in the continental areas and their borders; whereas oscillations of equal magnitude would have no corresponding effect in the bed of the ocean generally, believed as it is to have a mean depth of nearly 13,000 feet. The greatest depths of the sea do not exceed the greatest heights of the land; it may, therefore, seem strange that the mean depth of the sea should exceed the mean height of the land six times, even taking the lowest estimate of the ocean depths as given by the late deep-sea soundings. This apparent anomaly arises from the fact that the extreme heights of the land are exceptional and confined to a small part of its surface; while the ocean maintains its great depth over enormous areas.

It is evident that, during the recent periods of the earth's history, there have been great subsidences and elevations of the land; many raised beaches are 1,000 to 1,200 feet above sea-level. Dana, following Darwin's theory of Atoll formation, terms the Atoll a memorial of a departed land, and considers that the great Pacific subsidence was contemporaneous with the post-glacial upheaval in the north.

From all that we know of the extreme slowness of the upward and downward movements which bring about even slight geographical changes, we may infer that it would require a great lapse of time to cause the submarine and supramarine areas to change places, even if the ascending movements in the one region and the descending in the other were continuously in one direction. But we have only to appeal to the structure of the Alps, where there are so many shallow and deep-water

formations of various ages crowded into a limited area, to convince ourselves that mountain chains are the result of great oscillations of level. High land is not produced simply by uniform upheaval, but by a predominance of elevatory over subsiding movements. Where the ocean is extremely deep it is because the sinking of the bottom has been in excess, in spite of interruptions by upheaval.

Yet, persistent as may be the leading features of land and sea on the globe, they are not immutable. Some of the finest mud is doubtless carried to indefinite distances from the coast by marine currents, and we are taught by deep-sea dredgings that in clear water, at depths equalling the height of the Alps, organic beings may flourish, and their spoils slowly accumulate on the bottom. We also occasionally obtain evidence that submarine volcanoes are pouring out ashes and streams of lava in mid-ocean as well as on land, and that wherever mountains like Etna, Vesuvius, and the Canary Islands are now the site of eruptions, there are signs of accompanying upheaval, by which beds of ashes full of recent marine shells have been uplifted many hundred feet. We need not be surprised, therefore, if we learn from geology that the continents and oceans were not always placed where they now are, although the imagination may well be overpowered when it endeavours to contemplate the amount of time required for such revolutions.

The chalk formation consists of masses of foraminiferal ooze, one to two thousand feet in thickness, and was certainly formed in an ocean of considerable depth; but it now constitutes the surface over many thousands of square miles in the whole district of central Europe from Ireland to Russia and thence into Asia. In the same way masses of Globigerina- and Radiolarian-ooze accumulated in a deep ocean are now found at the height of several thousand feet above the sea-level in the islands of the West Indies.

It was at one time supposed that among the great masses of stratified materials forming the earth's crust there were no rocks comparable to the deposits which are now accumulating upon the floors of the great oceans. But the discoveries of the last few years have proved that such is not the case. Among the formations of the older, as well as among those of the newer periods of the earth's history, we find great masses of calcareous and siliceous rocks—sometimes thousands of feet in thickness—entirely made up, as shown by the microscope, of the minute forms of life that cover the existing deep-ocean floors. The comparatively modern chalk has its counterpart in a number of older calcareous rocks, almost wholly built up of the shells of

foraminifera with coccoliths and similar minute organisms. Siliceous rocks crowded with the remains of radiolarians have been found of great thickness and at a number of different horizons among the older as well as among the younger stratified deposits of the earth's crust; and these vast masses of calcareous and siliceous rocks are now found elevated to form portions not only of the dry land, but of great mountain-chains, and may be seen exposed to our study at the height of several miles above the sea-level. In the face of these facts, it seems impossible to doubt that great interchanges have taken place between oceanic and continental areas of the globe; and this conclusion is placed beyond doubt when we come to study the distribution of the forms of terrestrial and marine life.

We have gained a great step in obtaining an approximate estimate of the number of millions of years in which the average aqueous denudation going on upon the land would convey seaward a quantity of matter equal to the volume of our continents; and this may afford us a gauge to the minimum of subterranean force necessary to counteract such levelling power of running water; but to discover a relation between the periods required for the operation of these great physical agencies and the rate at which species of organic beings vary, is at present wholly beyond the reach of our computation—though perhaps it may not prove eventually to transcend the powers of Man.

The rate of denudation in the Thames Valley, so far as the removal of matter in solution is concerned, has been calculated, on what appear to be very trustworthy data, by Prof. Prestwich (Anniversary Address to Geological Society, 1872), and by Mr. T. Mellard Reade for the whole of England ('Soluble Denudation,' Address Geological Society of Liverpool, 1877). For materials carried in suspension the admirable memoir on the Mississippi by Messrs. Humphreys and Abbot supplied the first data that could be relied upon by geologists. The subject has been discussed, in respect to other river basins, in the essays of J. Croll and Sir A. Geikie, and the average rate of subaërial denudation may be regarded as now fairly well ascertained. The various publications of the United States Geological Survey should be consulted by the student as supplying the most valuable details concerning the process of earth sculpture in the North American continent, and especially of affording illustrations of the joint action of the internal and external forces of the globe, in giving rise to the existing forms of its surface. In connection with this subject, the essays of Prof. W. H. Davis on the structure of Pennsylvania and New Jersey may be studied with advantage, and also the writings of Dutton, Gilbert, Spencer, and other American geologists on the warping of the earth's crust, and on the influence of this action in the formation of cañons, lakes, and other surface features. The zoological evidence upon the question of the permanence or mutability of oceanic and continental areas has been discussed by Mr. Blanford. (Anniversary Address to Geological Society, 'Quart. Journ. Geol. Soc.' vol. xlvi., 1890.)

SECTION II. CHRONOLOGICAL CLASSIFICATION OF AQUEOUS ROCKS

CHAPTER XI

PRINCIPLES ON WHICH THE CLASSIFICATION OF SEDIMENTARY ROCKS IS BASED

Aqueous, Volcanic, Plutonic, and Metamorphic rocks considered chronologically—Terms Primary, Secondary, and Tertiary; Palæozoic, Mesozoic, and Cainozoic explained—On the different ages of aqueous rocks—Principal tests of relative age: superposition, mineral characters, fossils and included fragments—Faunas and floras determined by conditions, geographical position, and geological age—William Smith's classification of British deposits by their organic remains—Danger of extending the palæontological method over wide areas—Homotaxy—Combination of physical and palæontological methods—Classification of Tertiary strata—Tabular view of fossiliferous strata.

Chronology of rocks.—In the first chapter it was stated that the four great classes of rocks—the aqueous, the volcanic, the plutonic, and the metamorphic—would each be considered, not only in reference to their mineral characters and mode of origin, but also to their relative age. In regard to the aqueous rocks, we have already seen that they are stratified, that some are calcareous, others argillaceous or siliceous, some made up of sand, others of pebbles; that some contain freshwater, others marine fossils, and so forth; but the student has still to learn which rocks, exhibiting some or all of these characters, have originated at one period of the earth's history, and which at another.

To determine this point in reference to the sedimentary and fossiliferous formations is more easy than in any other class; and it is therefore the most convenient and natural method to begin by establishing a chronology for these strata, and then to refer, as far as possible, to the same divisions the several groups of volcanic, plutonic, and metamorphic rocks. Such a system of classification is not only recommended by its greater clearness and facility of application, but is also best fitted to strike the imagination by bringing into one view the contemporaneous

revolution of the inorganic and organic creations of former times. For the sedimentary formations are most readily distinguished by the remains of different species of animals and plants which they enclose; and of these animals and plants one set after another has flourished and then disappeared from the earth, each set leaving its relics behind as 'fossils,' or, as they have been termed—not inaptly—'medals of creation.'

In the present work, therefore, the four great classes of rocks will form four parallel, or nearly parallel, columns in one chronological table. They will be considered as sets of monuments relating to contemporaneous, or nearly contemporaneous, series of events. Just as aqueous and fossiliferous strata are now formed in certain seas or lakes, while in other places volcanic rocks break out at the surface, so, at every era of the past, fossiliferous deposits and superficial igneous rocks were in process of formation contemporaneously; and at the same time deep-seated chemical and mechanical actions led to the complete crystallisation and recrystallisation of materials both of igneous and aqueous origin, thus giving rise to the rocks which we call plutonic and metamorphic.

The early geologists gave to all the crystalline and non-fossiliferous rocks the name of Primitive or Primary, under the idea that their formation was anterior to the appearance of life upon the earth; while the aqueous or fossiliferous strata were termed Secondary; and alluvia or other superficial deposits, Tertiary.[1] The meaning of these terms has, however, been gradually modified with advancing knowledge, and they are now used to designate great chronological divisions under which all geological formations can be classed, each of them being characterised by the presence of distinctive groups of organic remains rather than by any physical peculiarities of the strata themselves. The use of the term 'Primary' is now almost entirely abandoned, but the terms 'Secondary' and 'Tertiary' are still used, though with very different significations attached to them. To avoid the risk of misapprehension, geologists have introduced the term 'Palæozoic' for the rocks containing the oldest known forms of life, from παλαιόν, 'ancient,' and ζῶον, 'an organic being,' still retaining the terms 'secondary' and 'tertiary;' Professor Phillips, however, for the sake of uniformity, proposed 'Mesozoic' for secondary, from μέσος, 'middle,' &c.; and 'Cainozoic' for tertiary, from καινός, 'recent,' &c.; the terms 'mesozoic' or

[1] At a very early date it was noticed that certain hard rocks—like slates, flagstones, and graywackès, while containing fossils, were partially crystallised, and appeared to form a link between the 'Primary' and 'Secondary' rocks. These intermediate rocks were called by Werner and the older geologists 'Transition rocks.'

secondary and 'cainozoic' or tertiary may be employed as useful synonyms.

The periods of time covered by the Palæozoic were so great, as shown by the enormous thickness of the strata, that it is convenient to group the Palæozoic rocks in two great divisions. Some authors propose to call these divisions Proterozoic and Deuterozoic; but as these names have not come into general use, it will be convenient to speak of them as Older Palæozoic and Newer Palæozoic respectively. We thus find that the series of fossiliferous rocks fall naturally into the following four grand divisions or classes:

Cainozoic, or Tertiary.

Mesozoic, or Secondary.

Newer Palæozoic (Deuterozoic).

Older Palæozoic (Proterozoic).

We shall see in the sequel that each of these great *classes* of strata is divided into three *systems*.

It will also be shown that great masses of sedimentary rocks, some of them greatly metamorphosed, and associated with volcanic and plutonic rocks, are found underlying the Palæozoic or the strata containing the oldest known fossils.

Age of strata.—For reasons already stated, we proceed first to treat of the aqueous or fossiliferous formations, considered in chronological order or in relation to the different periods at which they have been deposited.

There are three principal tests by which we determine the age of a given set of strata: first, superposition; secondly, mineral character; and, thirdly, organic remains. Some aid can occasionally be derived from a fourth kind of proof, namely, the fact of one deposit including in it fragments of a pre-existing rock, by which the relative ages of the two may, even in the absence of all other evidence, be determined.

Superposition.—The first and principal test of the age of one aqueous deposit, as compared with another, is relative position. It has been already stated that, where strata are horizontal, the bed which lies uppermost is the newest of the whole, and that which lies at the bottom the most ancient. Thus a series of sedimentary formations are like volumes of history, in which each writer has recorded the annals of his own times, and then laid down the book, with the last written page uppermost, upon the volume in which the events of the era immediately preceding were commemorated. In this manner a lofty pile of chronicles is at length accumulated; and they are so arranged as to indicate, by their position alone, the order in which the events recorded in them have occurred.

In regard to the crust of the earth, however, there are some regions where, as the student has already been informed, the beds have been disturbed, and sometimes extensively thrown over and turned upside down But an experienced geologist can rarely be deceived by ese exceptional cases. When he finds that the strata are fractured, curved, inclined, or vertical, he knows that the original order of superposition may be doubtful, and he then endeavours to find sections in some neighbouring district where the strata are horizontal, or only slightly inclined. Here, the true order of sequence of the entire series of deposits being ascertained, a key is furnished for settling the chronology of those strata where the displacement is extreme.

It should be remembered, however, that while this order of sequence is invariable, all the members of the series may not everywhere be present. Certain formations may never have been deposited in a particular area, or, if deposited, they may have been removed by denudation before later ones were thrown down. Thus one of the youngest members of the series may be found resting directly on one of the oldest.

Mineral character.—The same rocks may often be observed to retain for miles, or even hundreds of miles, the same mineral peculiarities, if we follow the planes of stratification, or trace the beds, if they be undisturbed, in a horizontal direction. But if we pursue them vertically, or in any direction transverse to the planes of stratification, this uniformity ceases almost immediately. In that case we can scarcely ever penetrate a stratified mass for a few hundred yards without beholding a succession of extremely dissimilar rocks, some of fine, others of coarse, grain, some of mechanical, others of chemical, origin; some calcareous, others argillaceous, and others siliceous. These phenomena lead to the conclusion that rivers, wind, and marine currents have dispersed the same sediment over wide areas at one period, but at successive periods have caused the accumulation, in the same region, of very different kinds of materials. The first observers were so astonished at the vast spaces over which they were able to follow the same homogeneous rocks in a horizontal direction, that they came hastily to the opinion that the whole globe had been environed by a succession of distinct aqueous formations, disposed round the nucleus of the planet, like the concentric coats of an onion. But although, in fact, some formations, like the chalk, may be continuous over districts as large as the half of Europe, or even more, yet most of them either terminate within narrower limits, or soon change their lithological character. Sometimes they thin out gradually, as if the supply of

sediment had failed in that direction, or they come abruptly to an end, as if we had arrived at the borders of the ancient sea or lake which served as their receptacle. It no less frequently happens that they vary in mineral aspect and composition, as we pursue them horizontally. For example, we trace a limestone for a hundred miles, until it becomes more arenaceous, and finally passes into sand, or sandstone. We may then follow this sandstone, already proved by its continuity to be of the same age, throughout another district a hundred miles or more in length.

Organic remains.—This character must be used as a test of the age of a formation or of the contemporaneous origin of two deposits in distant places, under very much the same restrictions as the test of mineral composition.

First, the same fossils may be traced over wide regions if we examine strata in the direction of their planes, although by no means for indefinite distances. Secondly, while the same fossils prevail in a particular set of strata for hundreds of miles in a horizontal direction, we seldom meet with the same remains for many fathoms, and very rarely for several hundred yards, in a vertical direction, or a direction transverse to the strata. This fact has now been verified in almost all parts of the globe, and has led to the conviction that, at successive periods of the past, the same area of land and water has been inhabited by distinct assemblages of species of animals and plants. It appears that from the remotest periods there has been ever a coming in of new organic forms, and a dying out or extinction of those which pre-existed on the earth: some species have endured for a longer, others for a shorter, time; while none have ever re-appeared after once dying out. The law which has governed the succession of species, whether we adopt or reject the theory of evolution, seems to be expressed in the verse of the poet,—

> Natura il fece, e poi ruppe la stampa.—ARIOSTO.
>
> Nature made him, and then broke the die.

And this circumstance it is which confers on fossils their highest value as chronological tests, giving to each of them, in the eyes of the geologist, that authority which belongs to contemporary medals in history.

The same cannot be said of each peculiar variety of rock; for some of these, as red marl and red sandstone for example, may occur at once at the top, bottom, and middle of the entire sedimentary series, exhibiting in each position so perfect an identity of mineral aspect as to be undistinguishable. Such exact repetitions, however, of the same mixtures of sediment

have not often been produced, at distant periods, in precisely the same parts of the globe; and, even where this has happened, we are not in any danger of confounding together the monuments of remote eras, when we have studied their embedded fossils and their relative position.

Zoological provinces.—It was remarked that the same species of organic remains cannot be traced horizontally, or in the direction of the planes of stratification, for indefinite distances. This might have been expected from analogy; for when we inquire into the present distribution of living beings, we find that the habitable surface of the sea and land may be divided into a considerable number of distinct areas or provinces, each peopled by a peculiar assemblage of animals and plants. The extent of these separate divisions and the origin of their inhabitants depend on many causes, of which climate, though certainly an important, is by no means the only one.

As, therefore, different seas and lakes are inhabited, at the same period, in different zones and at various depths, by distinct assemblages of aquatic animals and plants, and as the lands adjoining these may be peopled by varied terrestrial species, it follows that distinct fossils will be embedded in contemporaneous deposits. If it were otherwise—if the same species abounded in every climate, or in every part of the globe where, so far as we can discover, a corresponding temperature and other conditions favourable to their existence are found—the identification of mineral masses of the same age, by means of their included organic contents, would be a matter of even greater certainty than it really is.

Nevertheless, the extent of some single zoological provinces, especially those of marine animals, is very great; and our geological researches have proved that the same laws prevailed at remote periods; for the fossils are often identical throughout wide spaces, and in detached deposits, consisting of rocks, varying widely in their mineral nature.

The doctrine here laid down will be more readily understood if we reflect on what is now going on in the Mediterranean. That entire sea may be considered as one zoological province; for, although certain species of mollusca and zoophytes may be very local, and each region (according to its depth, the temperature and saltness of the water, and other conditions) has probably some species peculiar to it, still a considerable number are common to the whole Mediterranean. If, therefore, at some future period, the bed of this inland sea should be converted into land, the geologist might be enabled, by reference to organic remains, to prove the contemporaneous origin of various

mineral masses scattered over a space equal in area to the half of Europe.

Deposits, for example, are well known to be now in progress in this sea in the deltas of the Po, Rhone, Nile, and other rivers, which differ as greatly from each other in the nature of their sediment as does the mineral composition of the mountains which they drain. There are also other quarters of the Mediterranean, as off the coast of Campania, or near the base of Etna, in Sicily, or in the Grecian Archipelago, where another class of rocks is now forming; where showers of volcanic ashes occasionally fall into the sea, and streams of lava overflow its bottom; and where, in the intervals between volcanic eruptions, beds of sand and clay are frequently derived from the waste of cliffs, or the turbid waters of rivers. Limestones, moreover, such as the Italian travertins, are here and there precipitated from the waters of mineral springs. In all these detached formations, so diversified in their lithological characters, the remains of the same species of shells, corals, crustacea, and fish are becoming enclosed; or at least, a sufficient number must be common to the different localities to enable the zoologist to refer them all to one contemporaneous assemblage of species.

There are, however, certain combinations of geographical circumstances which cause distinct provinces of animals and plants to be separated from each other by very narrow limits; and hence it must happen that strata, on the same geological horizon, will be sometimes formed in contiguous regions, differing widely both in mineral contents and organic remains. Thus, for example, the testacea, zoophytes, and fish of the Red Sea are, as a group, distinct from those inhabiting the adjoining parts of the Mediterranean, the narrow isthmus of Suez having acted as an efficient barrier. Calcareous formations have accumulated on a great scale in the Red Sea in modern times, and fossil shells of existing species are well preserved therein; and we know that at the mouth of the Nile large deposits of mud are amassed, including the remains of Mediterranean species. It follows, therefore, that if at some future period the bed of the Red Sea should be laid dry, the geologist might experience great difficulties in endeavouring to ascertain the relative age of these formations, which, although dissimilar both in organic and mineral characters, were of synchronous origin.

But there are some species of mollusca common to the Mediterranean and the Red Sea, and their presence would suggest to the geologist of the remote future a more or less complete synchronism.

In some parts of the globe the line of demarcation between

distinct provinces of animals and plants is not very strongly marked, especially where the change is determined by temperature, as it is in seas extending from the temperate to the tropical zone, or from the temperate to the Arctic regions. Here a gradual passage takes place from one set of species to another. In like manner, the geologist, in studying particular formations of remote periods, has sometimes been able to trace the gradation from one ancient province to another, by carefully observing the fossils of all the intermediate places. His success in thus acquiring a knowledge of the zoological or botanical geography of very distant areas has been mainly owing to this circumstance, that the mineral character has no tendency to be affected by climate. A large river may convey yellow or red mud into some part of the ocean, where it may be dispersed by a current over an area several hundred leagues in length, so as to pass from the tropics into the temperate zone. If the bottom of the sea be afterwards upraised, the organic remains embedded in such yellow or red strata may indicate the different animals or plants which once inhabited at the same time the temperate and equatorial regions.

It is a general rule that groups of the same species of animals and plants may extend over wider areas than deposits of homogeneous composition; and thus palæontological characters are of more importance in geological classification than the test of mineral composition.

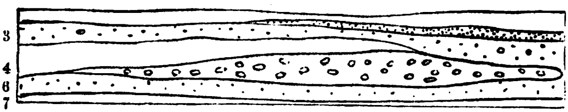
Test by included fragments of older rocks.—It was stated that proof may sometimes be obtained of the relative date of two formations, by fragments of an older rock being included in a newer one. This evidence may sometimes be of great use, where a geologist is at a loss to determine the relative age of two formations from want of clear sections exhibiting their true order of position, or because the strata of each group are vertical. In such cases we sometimes discover that the more modern rock has been in part derived from the degradation of the older. Thus, for example, we may find chalk in one part of a country, and in another strata of clay, sand, and pebbles. If some of these pebbles consist of that peculiar flint, of which layers more or less continuous are characteristic of the Chalk, and which include fossil shells, sponges, and foraminifera of Cretaceous species, we may confidently infer that the chalk was the older of the two formations.

Chronological groups.—The separate groups into which the fossiliferous strata may be divided are more or less numerous, according to the views of classification which different geologists may entertain; but when we have adopted a certain

system of arrangement we immediately find that a few only of the entire series of groups occur one upon the other in any single section or district.

The thinning out of individual strata was before described (p. 37). But let the annexed diagram represent seven fossili-

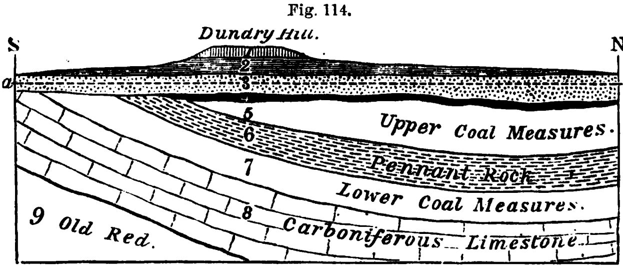
Fig. 113.



ferous groups, instead of as many strata. It will then be seen that in the middle all the superimposed formations are present; but in consequence of some of them thinning out, No. 2 and No. 5 are absent at one extremity of the section, and No. 4 at the other.

In another diagram (fig. 114) a true section of the geological formations in the neighbourhood of Bristol and the Mendip Hills is presented to the reader, as laid down on a natural scale by Sir A. Ramsay, where the newer groups 1, 2, 3, 4 rest

Fig. 114.



Section South of Bristol. (A. C. Ramsay.)

Length of section 4 miles. *a, b.* Level of the sea.

1. Inferior Oolite. 2. Lias. 3. New Red Sandstone. 4. Dolomitic or magnesian conglomerate. 5. Upper coal measures (shales, &c.). 6. Pennant rock (sandstone). 7. Lower coal measures (shales, &c.). 8. Carboniferous or mountain limestone, with lower limestone shale at its base. 9. Old Red Sandstone.

unconformably on, and overlap, the formations 5, 6, 7, and 8. At the southern end of the line of section we meet with the beds No. 3 (the New Red Sandstone) resting immediately on Nos. 7 and 8, while farther north, as at Dundry Hill in Somersetshire, we have eight groups superimposed one upon the other, comprising all the strata from the inferior oolite, No. 1, to the coal and

carboniferous limestone. The limited horizontal extension of the groups 1 and 2 is owing to subsequent denudation, as these formations end abruptly, and have left outlying patches to attest the fact of their having originally covered a much wider area.

In order, therefore, to establish a chronological succession of fossiliferous groups, a geologist must begin with a single section in which several sets of strata lie one upon the other. He must then trace these formations, by attention to their mineral character and fossils, continuously as far as possible, from the starting-point. As often as he meets with new groups, he must ascertain their age, relatively to those first examined, by superposition, and thus learn how to intercalate them in a tabular arrangement of the whole.

By this means the German, French, and English geologists have determined the succession of strata throughout the greater part of Europe, and have adopted pretty generally the groups enumerated in the table at the end of this chapter, p. 145, almost all of which have their representatives in the British Islands.

It must be understood, however, that, although in a given locality there may be a physical break—unconformity—and also a palæontological break—change in fossils—between two successive groups of strata, these evidences of lapse of time will not be discovered universally and wherever the two groups are present. Somewhere or other, strata of intervening age will be found to exist; or the groups will pass insensibly one into the other; in this way our classificatory distinctions will be found to break down.

All stratigraphical schemes are therefore more or less artificial and arbitrary; and they cannot be applied universally, for the 'breaks,' on which such schemes are based, did not occur contemporaneously over the whole globe.

From what has been stated, it may be accepted as a general but not a perfectly strict truth, that strata of different countries which contain the same species of fossils are of similar geological age. Such strata are said to be 'equivalent,' or 'on the same geological horizon,' and these terms are used in a very wide sense. But the strata containing the same species of fossils may be widely separated, geographically, and this fact is opposed to the idea of exact contemporaneity, for it took time for the species to disperse themselves over wide areas.

Chronological sequence of British strata.—The principle that strata, whatever their mineral characters, and however disturbed in their positions, *may be identified by their organic remains*, was first clearly enunciated at the end of the last

century by the famous William Smith, who has been justly called 'the Father of English Geology.' It so happens that in England we find, within a very small area, representatives of the whole series of sedimentary formations—lying in their proper sequence, and crowded with exquisitely preserved fossils, but in slightly tilted positions, and with their edges exposed by denudation. We who live in this country have therefore exceptional facilities for studying stratigraphical geology, and for making out the nature and succession of the faunas and floras which distinguish the several sedimentary formations. As a matter of fact, the order of succession of strata was first determined in the British Islands by William Smith and his followers, and the scheme of classification which he elaborated was gradually extended from this country to the continent of Europe, and thence to other parts of the world. The names still applied to the principal, and even to many of the subordinate, groups of strata are those which were given to them by William Smith or his followers.

William Smith's table of strata published with the first edition of his geological map of England and Wales, in 1815–16, showed the true order of succession of the British formations from the carboniferous limestone to the chalk, inclusive. With respect to the rocks which underlie the carboniferous, however, this great pioneer in geological investigation found himself unable to apply the important principles he had discovered; but a quarter of a century later the labours of Sedgwick, Murchison, and Lonsdale, carried on upon the lines laid down by Smith, resulted in the establishment of the older geological systems as understood at the present day. With respect to the strata overlying the chalk, Smith fell into some serious errors, which were only finally got rid of by the extension of the palæontological method advocated in the first edition of the 'Principles of Geology.'

Caution necessary in using the Palæontological Method.—But, from what we have said in preceding paragraphs, it will be obvious that the use of fossils for the identification of strata calls for a certain amount of caution.

In the first place, it is obviously necessary that we should satisfy ourselves that the fossils we find in a bed are really the remains of organisms that were living when the beds containing them were deposited.

William Smith made out his order of succession of strata in the first instance in the district between Bath and Bristol, while making a survey for the construction of a canal. He soon saw, however, that besides the regularly stratified formations, clay, sand, and limestone, each containing its peculiar ('characteris-

tic') fossils, there were masses of sand and gravel in which all these fossils were found mingled indiscriminately. Careful examination, however, soon convinced him that the fossils in the gravel were all *derived* ones, that is, had been washed out of older beds; and this fact was inferred from their waterworn characters, the differences in their mode of mineralisation, and the circumstance that they often contained portions of a matrix quite different from that of the deposit in which they are now found. In appealing to fossils as indicating the geological age of a stratum, therefore, we must be perfectly satisfied that they belong to the formation, and are not derived. The importance of the principle will be seen when we come to study the strata known as the 'crags.'

In the second place, we must remember that (inasmuch as distinct forms of shells, corals, sponges, &c., inhabit different depths of the ocean, and particular assemblages of animals and vegetables flourish on sandy or muddy bottoms respectively) strata formed in the same district, during a particular period cannot be expected to exhibit *identical* fossils. Geologists soon learn to recognise that each period has its shallow-water and its deep-water forms; and that different assemblages of species occur in the clays, sands, and limestones of the same formation.

In the third place, it must be remembered that, as we have a geographical distribution of life-forms at the present day, there are clear evidences of a similar geographical distribution of animals and vegetables during the earlier periods of the earth's history. Hence, while within a more or less limited area we may expect to find a particular assemblage of fossils in a geological formation, we must be prepared in distant areas to find these particular fossils more or less completely wanting, and their place taken by an equivalent or representative group of fossils, belonging to the same period, but to a different zoological province.

We thus see that the fossil flora or fauna [1] found in a formation at a particular locality is a function (to use a mathematical expression) of three variables. The assemblage of life-forms depends *first* on the conditions that prevailed when the beds were deposited—such as depth of water, climate, nature of sea-bottom, &c.; *secondly*, on the particular zoological province in which the locality was situated; and *thirdly*, on the geological period at which the beds were formed. We must always be on our guard to avoid assigning to differences of geological age

[1] The assemblage of animal forms in a particular area or stratum is called by naturalists its 'fauna,' and the assemblage of plants its 'flora.' Thus we speak of 'the British flora,' 'the Mediterranean fauna,' 'the Cretaceous fauna,' 'the Carboniferous flora,' &c.

changes of flora or fauna which may be due to differences of condition or of geographical position.

Limits of the Palæontological Method. Homotaxy.—There is another important consideration to which the attention of geologists was especially called by the late Mr. Godwin-Austen. Upon a gradually rising or sinking ocean-floor different areas may *successively* exhibit the same peculiarities of depth of water, temperature, &c.; and the forms of life which affect those conditions may be naturally expected to migrate from the old areas where the conditions have become unfavourable, into those new areas where the favourable conditions appear. Thus, in the stratum known as the Upper Greensand, which was evidently deposited in shallow water near a sinking coast line, belts of similar sediment of different age, but containing the same fossils, would be successively formed, and these will be taken by the geologist to be of contemporaneous formation. It is nevertheless evident that long periods of time may have elapsed between the deposition of one part of the Upper Greensand and another part of the same stratum or formation.

This brings us to the consideration of the meaning of the term 'synchronous' or 'contemporaneous' as employed by the geologist. Even the historian employs such a term with considerable latitude; but geologists, who are quite unable to assign terms of years for the great periods with which they have to deal, must necessarily use the word contemporary in a much more general sense even than the historian. Two beds are said to be contemporary by the geologist, when the time between the periods of their deposition does not appear to have been sufficient for any marked change in the forms of animal and vegetable life. But, as forms may migrate without change, the term 'geological contemporaneity' can have only a very general application. Of two great systems of strata in distant parts of the globe it can frequently only be said that they have a like position in the great geological record. In these cases, as pointed out by the late Professor Huxley, it is safer to employ the term 'homotaxy,' signifying a similarity of arrangement, instead of 'contemporaneity' or 'synchronism,' which conveys the idea of absolute identity in time.

Frequent unconformability of strata.—Where the widest gaps appear in the sequence of the fossil forms, as between the Permian and Triassic rocks, or between the Cretaceous and Eocene, examples of stratigraphical unconformability are very frequent. But they are also met with in some part or other of the world at the junction of almost all the other principal formations, and sometimes the subordinate divisions of any one

of the leading groups may be found lying unconformably on another subordinate member of the same. Instances of such irregularities in the mode of succession of the strata are the more intelligible as we extend our survey of the fossiliferous formations over wider areas, for we are continually bringing to light deposits of intermediate date, which have to be intercalated between those previously known; these deposits reveal to us a long series of events, which, antecedently to such discoveries, were quite unsuspected by us.

But while unconformability nvariably bears testimony to a lapse of unrepresented time, the conformability of two sets of strata in contact by no means implies that the newer formation immediately succeeded the older one. It simply indicates that the ancient rocks were subjected to no movements of such a nature as to tilt, bend, or break them before the more modern formation was superimposed. It does not show that the earth's crust was motionless in the region in question, for there may have been a gradual sinking or rising, extending uniformly over a large area, and yet during such movement the stratified rocks may have retained their original horizontality of position. Strata possessing very different animal remains and different kinds of rock may still be conformable, yet great changes must have occurred. There may have been a conversion of a wide area from sea into land and from land into sea, and during these changes of level some strata may have been slowly removed by aqueous action, and after this new strata may be superimposed, differing perhaps in date by thousands of years or centuries, and yet resting conformably on the older set. There may even be a blending of the materials constituting the older deposit with those of the newer, so as to give rise to a passage in the mineral character of the one rock into the other as if there had been no break or interruption in the depositing process.

Imperfection of the record.—Although, by the frequent discovery of new sets of intermediate strata, the transition from one type of organic remains to another is becoming less and less abrupt, yet the entire series of records appears to the geologists now living far more fragmentary and defective than it seemed to their predecessors a century ago. The earlier inquirers, as often as they encountered a break in the regular sequence of formations, connected it, theoretically, with a sudden and violent catastrophe, which had put an end to the regular course of events that had been going on uninterruptedly for ages, annihilating at the same time all or nearly all the organic beings which had previously flourished, after which, order being re-established, a new series of events was initiated. In proportion as our faith in

these views grows weaker, and the phenomena of the organic or inorganic world presented to us by geology seem explicable on the hypothesis of gradual and insensible changes, varied only by occasional convulsions, on a scale comparable to, though it may be far greater than, any witnessed in historical times; and in proportion as it is thought possible that former fluctuations in the organic world may be due to the indefinite variability of species without the necessity of assuming new and independent acts of creation, the number and magnitude of the gaps which still remain, or the extreme imperfection of the record, become more and more striking, and what we possess of the ancient annals of the earth's history appears insignificant when contrasted with that which has been lost.

It is observed that strata, in proportion as they are of newer date, bear the nearest resemblance in mineral character to those which are now in process of formation in seas or lakes, the newest of all consisting principally of soft mud or loose sand, in some places full of shells, corals, or other organic bodies—animal or vegetable—in others wholly devoid of such remains. The farther we recede from the present time, and the higher the antiquity of the formations which we examine, the greater, as a general rule, are the changes which the sedimentary deposits have undergone. Time, as has already been explained, has multiplied the effects of alteration by pressure and solution, and the modifications brought about by heat, pressure, contortion, upheaval, and denudation. The organic remains have sometimes been obliterated entirely, or the mineral matter of which they were composed has been removed and replaced by other substances.

Why newer groups should be studied first.—We likewise observe that the older the rocks the more widely do their organic remains depart from the types of the living creation. Thus we find in the newer Tertiary rocks a few species which no longer exist, mixed with many living ones, and then, as we go farther back, many genera and families at present unknown are met with, until we come to strata in which the fossil relics of existing species and genera are nowhere to be detected, while families and orders of animals and plants wholly unrepresented in the living world begin to be conspicuous.

When we study, therefore, the geological records of the earth and its inhabitants, we find, as in human history, the defectiveness and obscurity of the monuments always increasing, the remoter the era to which we refer; the rocks becoming more generally altered and crystalline the older they are, and the difficulty of determining their true chronological relations

becoming more and more enhanced, especially when we are comparing those which were formed in very distant regions of the globe. Hence we advance with securer steps when we begin with the study of the geological records of later times, proceeding from the newer to the older, or from the more to the less known.

In thus inverting what might at first seem to be the more natural order of historical research, we must bear in mind that each of the periods above enumerated, even the shortest, such as the Post-tertiary, or the Pliocene, Miocene, or Eocene, embraces a succession of events of vast extent, so that to give a satisfactory account of what we already know of any one of them would require many volumes. When, therefore, we study one of the newer groups before endeavouring to decipher the monuments of an older one, it is like endeavouring to master the history of our own country and that of some contemporary nations, before we enter upon Roman History; or like investigating the annals of Ancient Italy and Greece before we approach those of Egypt and Assyria.

The geological record is so much more complete in the case of the Tertiary or youngest strata, that geologists have been led to adopt principles of chronological classification with respect to them which are somewhat different from those that have been found suitable when dealing with the much more fragmentary records of the Mesozoic and Palæozoic Eras.

The Tertiary or Cainozoic strata were so called because they were all posterior in date to the Secondary series, of which last the chalk or Cretaceous constitutes the newest group. The whole of the Tertiaries were at first confounded with the superficial alluvia of Europe; and it was long before their real extent and thickness, and the various ages to which they belong, were fully recognised. They were observed to occur in patches, some of freshwater, others of marine origin, their geographical extent being usually small as compared with that of the Secondary formations, and their position often suggesting the idea of their having been deposited in different bays, lakes, estuaries, or inland seas, after a large portion of the space now occupied by Europe had already been converted into dry land.

The first deposits of this class of which the characters were accurately determined, were those occurring in the neighbourhood of Paris, described in 1810 by Cuvier and Brongniart. They were ascertained to consist of successive sets of strata, some of marine, others of freshwater origin, lying one upon the other. The fossil shells and corals were found to be almost all of unknown species, but to have a general affinity with those now inhabiting warmer seas. The bones and skeletons of

land animals, some of them of large size, and belonging to more than forty distinct species, were examined by Cuvier, and declared by him not to agree either specifically, or even generically, with any hitherto observed in the living creation.

Strata were soon afterwards brought to light in the vicinity of London, and in Hampshire, which, although dissimilar in mineral composition, were justly inferred by Webster to be of the same age as those of Paris, because the greater number of the fossil shells were specifically identical. For the same reason, rocks found in the Gironde, in the South of France, and at certain points in the North of Italy, were suspected to be of contemporaneous origin.

Another important discovery was soon afterwards made by Brocchi in Italy. He investigated the argillaceous and sandy deposits replete with shells, which form a low range of hills flanking the Apennines on both sides, from the plains of the Po to Calabria. These lower hills were called by him the Subapennines, and were found to consist of strata chiefly marine, and newer than those of Paris and London.

Another tertiary group occurring in the neighbourhood of Bordeaux and Dax, in the South of France, was examined by Basterot in 1825; and he described and figured several hundred species of shells, which differed for the most part both from the Parisian series and those of the Subapennine hills. It was soon, therefore, suspected that this fauna might belong to a period intermediate between that of the Parisian and Subapennine strata, and it was not long before the evidence of superposition was brought to bear in support of this opinion; for other strata contemporaneous with those of Bordeaux were observed in one district (the Valley of the Loire) to overlie the Parisian formation, and in another (in Piedmont) to underlie the Subapennine beds. The first example of these was pointed out in 1829 by Desnoyers, who ascertained that the sand and marl, full of sea-shells and corals, occurring near Tours, in the basin of the Loire, and called Faluns, rest upon a lacustrine formation, which constitutes the uppermost subdivision of the Parisian group, extending continuously throughout a great table-land intervening between the basin of the Seine and that of the Loire. The other example occurs in Italy, where strata containing many fossils similar to those of Bordeaux, were observed by Bonelli and others in the environs of Turin, subjacent to strata belonging to the Subapennine group of Brocchi. Long afterwards, the superficial layers which cover many of these, and which have their stones scratched and polished, were found to contain Arctic shells.

Value of fossil mollusca in classification.—It will be observed that in the foregoing allusions to organic remains the shell-bearing mollusca are selected as the most useful and convenient class for the purposes of general classification. In the first place, they are more universally distributed through strata of every age than any other organic bodies. Those families of fossils which are of rare and casual occurrence are of little use in establishing a chronological arrangement: If we have plants alone in one group of strata and the bones of mammalia in another, we can draw no conclusion respecting the affinity or discordance of the organic beings of the two epochs compared; and the same may be said if we have plants and vertebrated animals in one series and only shells in another. Although corals are more abundant, in a fossil state, than plants, reptiles, or fish, they are still rare in comparison with shells, because they are more dependent for their well-being on the constant clearness of the water, and are, therefore, less likely to be included in rocks which endure in consequence of their thickness and the copiousness of sediment which prevailed when they originated. The utility of the mollusca is, moreover, enhanced by the circumstance that some forms are proper to the sea, others to the land, and others to fresh water. Rivers scarcely ever fail to carry down into their deltas some land-shells, together with species which are at once fluviatile and lacustrine. By this means we learn what terrestrial, freshwater, and marine species coexisted at particular eras of the past; and having thus identified strata formed in seas with others which originated contemporaneously in inland lakes, we are then enabled to advance a step farther, and show that certain quadrupeds or aquatic plants, found fossil in lacustrine formations, inhabited the globe at the same period when certain fish, reptiles, and zoophytes lived in the ocean.

Among other characters of the molluscous animals, which render them extremely valuable in settling chronological questions in geology, may be mentioned, first, the wide geographical range of many species: and, secondly, what is probably a consequence of the former, the great duration in time of some species in this class, for they appear to have surpassed in longevity the greater number of the fish and mammalia. Had each species inhabited a very limited space, it could never, when embedded in strata, have enabled the geologist to identify deposits at distant points over large areas; or had they each lasted but for a brief period, they could have thrown no light on the connection of rocks placed far from each other in the chronological, or, as it is sometimes termed, the vertical series.

Classification of Tertiary strata.—In the first edition of the 'Principles of Geology' the whole of the Tertiary formations were divided into four groups, characterised by the percentage of recent shells which they contained. The lower tertiary strata of London and Paris were thought by Deshayes to contain only 3½ per cent. of recent species, and were termed Eocene. The middle tertiary of the Loire and Gironde had, according to the specific determinations of the same eminent conchologist, 17 per cent., and formed the Miocene division. The Subapennine beds contained 35 to 50 per cent., and were termed Older Pliocene, while still more recent beds in Sicily, which had from 90 to 95 per cent. of species identical with those now living, were called Newer Pliocene. The first of the above terms, Eocene, is derived from ἠώς, eos, *dawn*, and καινός, cainos, *recent*, because the fossil shells of this period contain an extremely small proportion of living species, which may be looked upon as indicating the dawn of the existing state of the molluscan fauna, no recent species (with one or two exceptions) having been detected in the older or secondary rocks.

The term Miocene (from μεῖον, meion, *less*, and καινός, cainos, *recent*) is intended to express a minor proportion of recent species (of mollusca), the term Pliocene (from πλεῖον, pleion, *more*, and καινός, cainos, *recent*), a comparative plurality of the same. It may assist the memory of students to remind them, that the *Mi*ocene contain a *mi*nor proportion, and *Pl*iocene a comparative *pl*urality of recent species; and that the greater number of recent species always implies the more modern origin of the strata.

Subsequently to this classification, Beyrich founded the 'Oligocene' as a division intermediate between the Eocene proper and the Miocene. This division includes the Lower Miocene formations of older writers, together with much of their Upper Eocene Series. Nummulites, so abundant in the Eocene, became scarce and degenerated in the Oligocene series, which in Europe contains very important freshwater beds with mammalian remains, as well as marine deposits.

Since the year 1830 the number of known shells, both recent and fossil, has largely increased, and their identification has been more accurate. Hence some modifications have been required in the classifications founded on less perfect materials. The Eocene, Oligocene, Miocene, and Pliocene periods have been made to comprehend certain sets of strata, of which the fossils do not always conform strictly, in the numerical proportions of recent to extinct species, with the definitions first given to those divisions or which are indicated in the etymologies of the terms.

There is such convenience in distinguishing between the earlier Tertiary strata in which only a small minority of the fossil shells are found living in the existing seas, and the later deposits in which a very considerable proportion of the shells are still living, that we shall follow the geologists of Eastern Europe and North America in adopting a twofold division for the great mass of the Cainozoic rocks. We shall speak of the earliest Tertiary strata as Older Tertiaries, as the term has long been in use in this country; in the United States, and in Eastern Europe, this division is often called 'Eogene.' The Newer Tertiaries of English authors are called by the Austrian geologists 'Neogene,' and by those of the United States 'Neocene.'

It will be convenient to give at this point a summary, in the

ABRIDGED GENERAL TABLE OF FOSSILIFEROUS STRATA

CLASSES of Strata representing ERAS of Time	SYSTEMS of Strata representing PERIODS of Time	STAGES of Strata representing EPOCHS of Time
CAINOZOIC (Tertiary)	PLEISTOCENE	Post-Glacial. Glacial. Pre-Glacial.
	NEWER TERTIARIES	Pliocene. Miocene (not known in Britain).
	OLDER TERTIARIES	Oligocene. Eocene. Paleocene (not known in Britain).
MESOZOIC (Secondary)	CRETACEOUS	Chalk. Upper Greensand and Gault. Neocomian.
	JURASSIC	Oolites. Lias. Rhætic.
	TRIASSIC	Keuper Muschelkalk (not known in Britain). Bunter.
NEWER PALÆOZOIC	PERMIAN	Upper Permian. Roth-todt-liegende.
	CARBONIFEROUS	Coal measures. Millstone grit. Lower limestones and shales.
	DEVONIAN	Upper Devonian. Middle Devonian. Lower Devonian.
OLDER PALÆOZOIC	SILURIAN	Ludlow. Wenlock. May Hill.
	ORDOVICIAN	Bala. Llandeilo. Arenig.
	CAMBRIAN	Upper Cambrian. Middle Cambrian. Lower Cambrian.

AGNOTOZOIC.—Eparchian or Algonkian strata.

form of a table, of the general system of classification of strata, according to their geological age, which has now been generally adopted by geologists.

It must be borne in mind that this classification of geologica periods is in the main the result of studies carried on in the British Islands and Western Europe, and that if the science of stratigraphical geology had originated in Eastern Europe, India, Australia, or the United States, the great divisions which would have been adopted and the limits between them would have been altogether different.

Even among European geologists there is considerable diversity in opinion and practice as to the delimiting and naming of the great geological systems, and of their principal subdivisions. Thus, some authors make the lower portion of the Cretaceous a distinct system, calling it 'Neocomian,' while others divide the Jurassic into two, the Liassic and Oolitic. It may be some aid to the memory to adopt the four great classes of strata, each including three systems, as shown in the Table. Some English authors still follow Murchison in combining the Silurian and Ordovician, and naming the latter 'Lower Silurian.'

The Table takes account only of marine formations; but it must be remembered that in addition to these there are great systems of strata of freshwater origin, like the Wealden and the Old Red Sandstone. Eventually it may be necessary to have two distinct schemes of classification for stratified rocks, one to include strata of marine origin, the other for freshwater and terrestrial deposits. The limits of the systems and other subdivisions in these two schemes, could not be expected to agree.

In giving names to the groups of strata of different orders of magnitude, and the divisions of time which they represent, we have followed the scheme proposed by the International Geological Congress, with the modifications suggested by Mr. Blanford.

The distribution of the several systems of strata and of their main subdivisions in the southern part of Great Britain is shown in the map forming the frontispiece to this volume.

The principles of geological classification have been discussed by Professor Huxley in his address to the Geological Society in 1862, on 'Geological Contemporaneity and Persistent Types of Life,' reprinted in his collected essays. The student should also consult Mr. Blanford's addresses to the Geological Society in 1889–90.

THE CAINOZOIC (TERTIARY) ERA

CHAPTER XII

THE PLEISTOCENE PERIOD WITH THE GLACIAL EPISODE

Use of the terms 'pleistocene,' 'recent,' and 'human'—Mollusca of the Pleistocene period—Mammalia of the Pleistocene period—Shorter duration of mammalian as compared with molluscan species—Geographical distribution of mammalia in Pleistocene times similar to that at present day—Remains of man—Flint implements—Shell mounds—Cavern deposits—Valley gravels—High- and low-level gravels—Brick earth—Loess—Lacustrine deposits—Estuarine deposits—Marine deposits—Subdivisions of the Pleistocene period—Pre-glacial—The Glacial period—Origin of Boulder clay—Glacial lakes and other phenomena of glaciated districts—Post-glacial, Pluvial, and Champlain periods—Palæolithic and Neolithic—Copper, Bronze, and Iron Ages.

Nomenclature and classification of the Pleistocene deposits.—The youngest of the divisions of the Newer-Tertiary system is known as the Pleistocene, or Post-pliocene. The terms 'Post-tertiary' and 'Quaternary' have also been applied to the period by some authors; but these names may fairly be objected to on the ground that they imply the existence of differences between these youngest strata and the other Tertiary rocks, which are not borne out when a careful comparison is made of their organic remains. The term 'Pleistocene,' proposed by Lyell in 1839 as a synonym for Newer Pliocene, was used by the late Edward Forbes as the equivalent of Post-pliocene, and has now passed into general use with that signification.

The very latest deposits of this period are sometimes distinguished by the terms 'recent' and 'human.' To the use of the former term it may be objected that cases constantly occur in which it is impossible to draw a boundary line between the recent and other Pleistocene deposits. The employment of the term 'human period' is equally inconvenient, seeing that geologists are by no means agreed as to the exact part of the Pleistocene period at which man made his appearance on the

earth, while some observers have even maintained that there is evidence of his existence in pre-Pleistocene times.

Characteristics of the fauna and flora of the Pleistocene deposits.—The shells found in these Pleistocene deposits belong, almost without exception, to species still living on the earth. It is worthy of remark, however, that the geographical distribution of these mollusca was in Pleistocene times very different from that of the present day. In not a few cases we find in the Pleistocene deposits of the British Islands and North America an assemblage of shells now only found in much higher latitudes, where the temperature of the sea is much colder than that both of the British Islands and of the Atlantic shore of the United States.

The shells figured below are only a few out of a large assemblage of living species, which, taken as a whole, bear

Fig. 115.
Ast rte borealis, Chem. sp. ½.

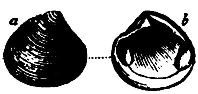


Fig. 116.
Leda lanceolata, Sow. ½.

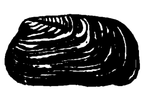


Fig. 117.
Saxicava rugosa, Lam. ½.

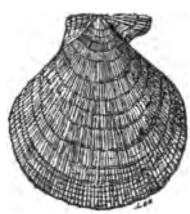


Fig. 118.
Pecten islandicus, Müll. ¼.

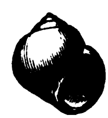


Fig. 119.
Natica clausa, Brod. & Sow. ½.

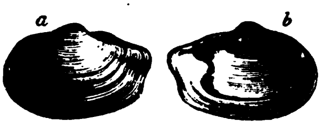
Fig. 120.
Trophon clathratum, L. Mag. 2 diams.

Northern shells common in the drift of the Clyde, in Scotland.

testimony to conditions far more arctic than those now prevailing in the Scottish seas. But a group of marine shells, indicating a still greater excess of cold, has been brought to light from glacial drift or clay on the borders of the estuaries of the Forth and Tay. This clay occurs at Elie in Fife, and at Errol in Perthshire; and has already afforded about thirty-five shells, all of living species, and now inhabitants of Arctic regions, such as *Leda truncata*, Brown, *Tellina calcarea*, Chem. (see figs. 121, 122), *Pecten grœnlandicus*, Sow., *Crenella lævigata*, Gray, *Crenella nigra*, Gray, and others, some of them first brought by Captain Sir E. Parry from the coast of Melville Island, latitude 76° N. These were all identified in 1863 by Dr. Torell, who had just returned from a survey of the seas around Spitzbergen, where he had collected no less than 150

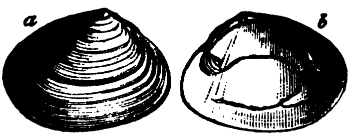
species of mollusca, living chiefly on a bottom of fine mud derived from the moraines of glaciers which protrude into the sea. He found that the fossil fauna of this Scotch glacial deposit exhibits

Fig. 121.



Leda truncata, Brown.
a. exterior of left valve.
b. interior of same.
Nat. size.

Fig. 122.

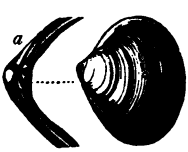


Tellina calcarea, Chem.
a. outside of left valve.
b. interior of same.

not only the species but also the peculiar varieties of mollusca now characteristic of very high latitudes. On the other hand, there are a few species of mollusca in the Pleistocene beds of this country which are now found living in much warmer climates. Of these *Corbicula* (*Cyrena*) *fluminalis*, Müll. (fig. 123), a shell found living in the Nile at the present day, may be taken as a conspicuous example.

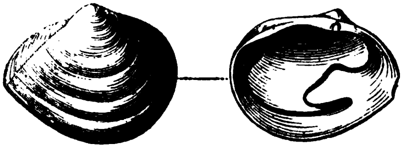
The great majority of the Pleistocene mollusca are found also in the underlying Pliocene deposits. But there are some striking examples of forms occurring in the Pleistocene which are quite unknown in any earlier formation. Of these *Tellina balthica*, L. (fig. 124), a shell still common in the British seas, is an interesting example.

Fig. 123.



Cyrena (*Corbicula*) *fluminalis*, Müll.; fossil. Grays, Essex, and living in the Nile. Nat. size.

Fig. 124.



Tellina balthica, L. Nat. size.

While the mollusca of the Pleistocene strata are so similar to those of the present day on the one hand, and to those of the Newer Pliocene on the other hand, there are the most striking differences exhibited, not only in the geographical distribution, but likewise in the specific forms of the *vertebrate* forms of life which flourished at these different periods; a part, and indeed often a very considerable part, of the mammalia found in Pleistocene deposits belonging to extinct species.

Relative longevity of species in the mammalia and

mollusca.—In 1830 [1] attention was called to the fact—which had not at that time attracted notice—that the association in the Pleistocene deposits of shells, exclusively of living species, with many extinct quadrupeds, betokened a longevity of species in the mollusca far exceeding that in the mammalia. Subsequent researches seem to show that this greater duration of the same specific forms in the class mollusca is dependent on a still more general law, namely, that the lower the grade of animals, or the greater the simplicity of their structure, the more persistent are they in general in their specific characters throughout vast periods of time. Those mollusca which are of more simple structure have varied at a slower rate than those of a higher and more complex organisation; the Brachiopoda, for example, more slowly than the Lamellibranchiata, while the latter have been more persistent than either the Gastropoda or the Cephalopoda. In like manner the specific identity of the characters of the Foraminifera, which are among the lowest types of the invertebrata, has outlasted that of the mollusca in an equally decided manner.

Teeth of Pleistocene mammalia.—To those who have never studied comparative anatomy, it may seem scarcely credible that a single bone, or even the fragment of a bone, taken from any part of the skeleton, may enable a skilful osteologist to distinguish, in many cases, the genus, and sometimes the species, of quadrupeds to which it belonged. Although few geologists can aspire to such knowledge, which must be the result of long practice and study, they will nevertheless derive great advantage from learning, what is comparatively an easy task, to distinguish the principal divisions of the mammalia by the forms and characters of their teeth.

The figures on pages 151 to 153 represent the teeth of some of the more common species and genera found in the alluvial and cavern deposits of the Pleistocene period.

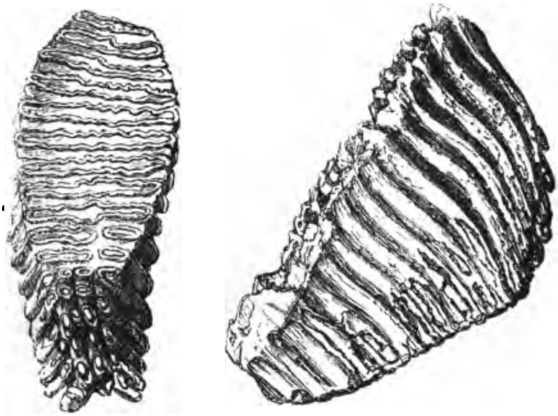
On comparing the grinding surfaces of the corresponding molars of the three species of elephants, fig. 125, it will be seen that the folds of enamel are most numerous in the Mammoth; fewer and wider, or more open, in *E. antiquus*, Falc.; and most open and fewest in *E. meridionalis*, Nesti, a Pliocene form. It will be also seen that the enamel in the molar of the *Rhinoceros tichorhinus*, Cuv. (fig. 127), is much thicker than in that of the *Rhinoceros leptorhinus*, Cuv. (fig. 126).

When a comparison is made between the mammalia found in the Pleistocene deposits of different parts of the earth's surface and the forms of life now inhabiting the same areas, we find

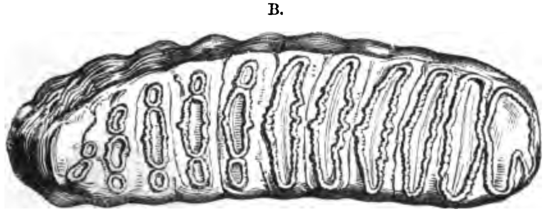
[1] *Principles of Geology*, 1st ed. vol. iii. p. 140.

Fig. 125.

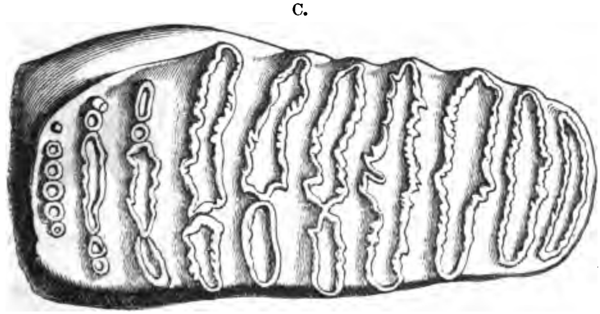
a A. *b*



B.



C.



Molar teeth of late Tertiary Elephants.

A. ***Elephas primigenius***, Blumenb. (or Mammoth). Molar of upper jaw, right side; one-third of natural size. Pleistocene. *a.* grinding surface. *b.* side view.

B. ***Elephas antiquus***, Falc. Penultimate molar; one-third of natural size. Pleistocene and Pliocene.

C. *Elephas meridionalis*, Nesti. Penultimate molar; one-third of natural size. Pliocene.

ample proof that the geographical distribution of these forms of terrestrial life was similar to what is found at the present day. This is well seen by the study of the bones which have been found in peat mosses and caves in Australia.

No remains of any European or Asiatic animal have been

Fig. 126.

Rhinoceros leptorhinus, Cuvier (*R. megarhinus*, Christol); fossil from freshwater beds of Grays, Essex; penultimate molar, lower jaw, left side; two-thirds of nat. size. Pleistocene and Newer Pliocene.

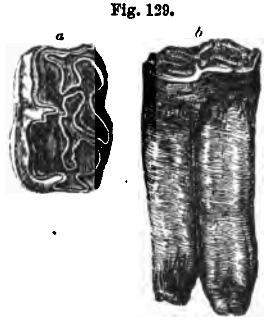
Fig. 127.

Rhinoceros tichorhinus, Cuvier; penultimate molar, lower jaw, left side; two-thirds of nat. size. Pleistocene.

Fig. 128.

Hippopotamus major, Nesti; from cave near Palermo; molar tooth, two-thirds of nat. size. Pleistocene. Living.

Fig. 129.



Horse.

Equus caballus, L. (common horse); from the shell-marl, Forfarshire; second molar, lower jaw. Recent.
a. grinding surface, two-thirds nat. size.
b. side view of same, half nat. size.

Fig. 130.

Deer.

Elk (*Cervus alces*, L.); recent; molar of upper jaw.
a. grinding surface.
b. side view; two-thirds of nat. size.

found in those deposits; the bones belong to those families of Marsupials, without exception, which are now existing in Australia. The animals were in some instances gigantic. The genera *Macropus* (Kangaroo), *Peramales* (Bandicoot), *Phalanger*, *Dasyurus*, and *Phascolomys* (Wombat), were represented

by the remains of gigantic and small species, some of which are extinct, while others still exist. A huge animal called

Fig. 131.

Ox.

Ox (*Bos taurus*, L.), from shell marl, Forfarshire; true molar, upper jaw; two-thirds nat. size. Living.
c. grinding surface.
d. side view; fangs uppermost.

Fig. 132.

a *b*

Bear.

a. canine tooth or tusk of bear (*Ursus spelæus*, Blumenb.); from cave near Liège.
b. molar of left side, upper jaw, one-third of nat. size. Pleistocene.

Fig. 133.

c *d*

Tiger.

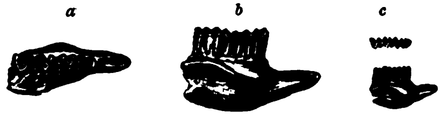
c. canine tooth of tiger (*Felis tigris*, L.). Living. ½ nat.
d. outside view of posterior molar, lower jaw; one-third of nat. size. Recent.

Fig. 134.

Hyæna spelæa, Goldf. (variety of *H. crocuta*, Zimm.); part of lower jaw. Kent's Hole, Torquay, Devonshire. One-third nat. size. Pleistocene. Living in Africa.

Fig. 135.

a *b* *c*



Teeth of *Arvicola intermedius*, E. T. Newton; a vole, or field-mouse, from the Norwich crag. Newer Pliocene.
a. grinding surface. *b.* side view of same. *c.* nat. size of *a* and *b*.

Diprotodon from its great front teeth, another, the *Nototherium*, and also *Protemnodon* and *Sthenurus* were found, and all were

marsupials. Another marsupial called *Thylacoleo*, probably of carnivorous habit, also abounded. Of the same geological age as these breccias are the bogs and swamp beds of the valleys of South Australia and Queensland, which contain *Diprotodon* and other marsupial remains. It is very noteworthy that marsupials alone should have lived in Australia in the Pleistocene age, for they are the only mammalia truly indigenous in that continent at the present time. It is one of the many instances of the persistence of a type on the same area, and it indicates long separation from other lands. This law of geographical relationship between the living and Pleistocene vertebrata is extremely interesting, and is not confined to the mammalia only. Thus, when New Zealand was first examined by Europeans, it was found to contain no indigenous land quadrupeds; but a small bird, wingless or with very rudimentary wings, abounded there, the smallest living representative of the Ostrich family, called the Kiwi by the natives (*Apteryx*). In the remains of the Pleistocene period in the same island, there are numerous well-preserved specimens of gigantic birds of the Struthious or Ostrich order, belonging to genera called by Owen *Dinornis* and *Palapteryx*, which are entombed in superficial deposits. These genera comprehended many species, some of which were four, some seven, others nine, and others eleven feet in height! No contemporary mammalia shared the land with this population of gigantic feathered bipeds.

Mr. Darwin, when describing the recent and Pleistocene mammalia of South America, dwelt much on the wonderful relationship of the extinct to the living types of that part of the world, inferring from such phenomena that the existing species are all related to the extinct ones which preceded them by the bond of common descent.

In the Pampas of South America the skeletons of ***Megatherium***, ***Megalonyx***, ***Mylodon***, ***Glyptodon***, ***Toxodon***, ***Macrauchenia***, and other extent forms, find their nearest analogues in the living Sloth, Armadillo, Cavy, Capybara, and Llama of that continent. The skeleton of one of these great extinct sloths is represented in fig. 136 on the opposite page. The fossil quadrumana, also associated with some of these forms in the Brazilian caves, belong to the Platyrrhine family of monkeys, now peculiar to South America. That the extinct fauna of Buenos Ayres and Brazil was not very ancient has been shown by its relation to deposits of marine shells, agreeing with those now inhabiting the Atlantic. Bones of great Carnivora have been found, and also of the Peccary. Moreover, human re-

mains have been got from the Brazilian caves with these bones. It is interesting to note that the Opossum, which belongs to a marsupial family peculiar to America, is found in these cave

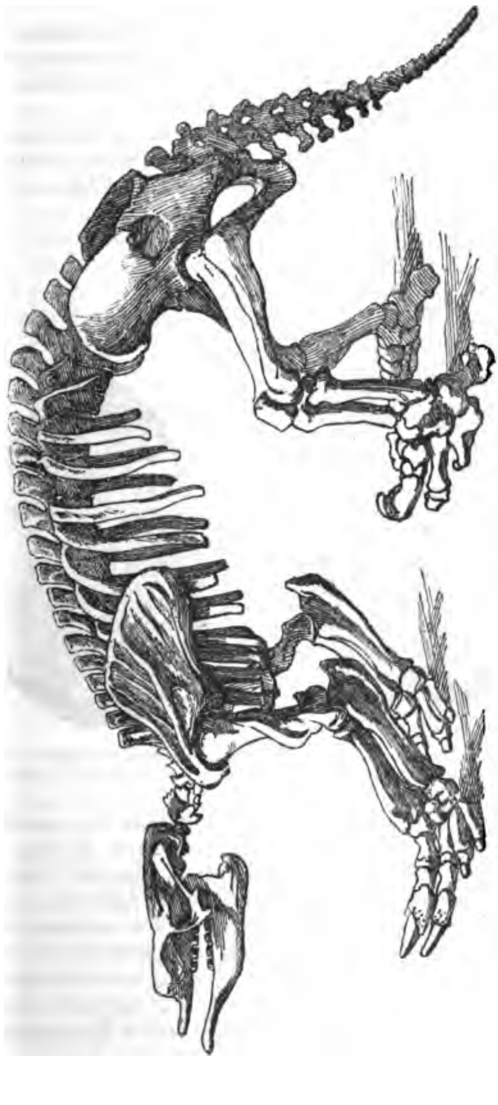


Fig. 136.

Scelidotherium leptocephalum, Owen. Skeleton restored. A gigantic sloth (Edentata) allied to the *Megatherium*, *Megalonyx*, and *Mylodon*. From the Pleistocene of Argentina.

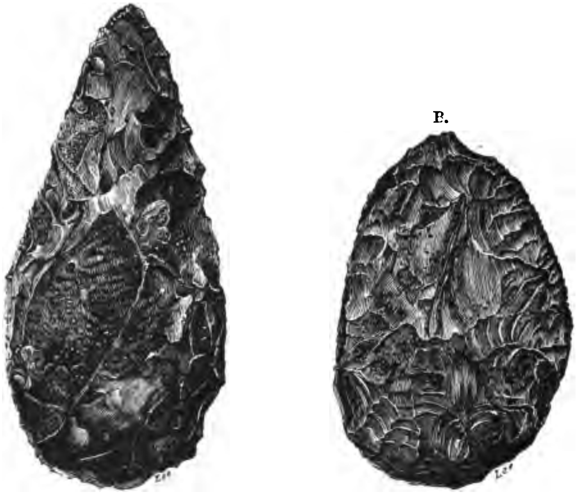
breccias, and it is not associated with any Australian kinds, neither, on the other hand, is any *Didelphys* (Opossum) found in Australia.

The old natural history provinces of this Pleistocene period were limited by natural boundaries and had their characteristic fauna. There was no mixture of European types with the South American or Australian, and the animals of Asia did not roam to the south, into Australia.

While we have no certain indication of the existence of human beings before the Pleistocene period, there is indisputable evidence that man existed on the earth at least during the latter

A. Fig. 137.

B.



Palæolithic flint implements.
A. Spear-head type. St. Acheul. One-third of the original size. B. Oval-shaped type. Mautort, near Abbeville. One-half of the original size.

portion of the Pleistocene, and that he was the contemporary of the remarkable forms of mammalia, many of them now extinct, which we have been describing. In 1847 Boucher de Perthes observed in an ancient alluvium at Abbeville, in Picardy, the bones of extinct mammalia associated in such a manner with flint implements of a rude type, as to lead him to infer that both the organic remains and the works of art were referable to one and the same period. This inference was soon after confirmed by Professor Prestwich, who found in 1859 a flint implement *in situ* in the same stratum at Amiens that contained the remains

of extinct mammalia. Since that time palæolithic stone implements have been found in many valley gravels on all the continents.

The flint implements found at Abbeville and Amiens (fig. 137) are different from those commonly called 'celts' (fig. 138). These celts, so often found in the recent formations, have a more regular oblong shape, the result of grinding, by which also a sharp edge has been given to them. The Abbeville implements found in gravel at different levels, as in Nos. 3 and 4, fig. 112, p. 111, in which bones of the Elephant, Rhinoceros, and other extinct mammalia occur, are always unground, having evidently been brought into their present form simply by the chipping off of fragments of flint by repeated blows, such as could be given by another stone.

Fig. 138.

Neolithic polished celt found at Cotton, Cambridgeshire, 1863. One-half of the original size.

Some of them are oval, others of a spear-headed form, no two exactly alike, and yet the greater number of each kind are obviously fashioned after the same general pattern, which is world-wide. Their outer surface is often white, the original black flint having been discoloured and bleached by exposure to the air, or by the action of acids as they lay in the gravel. They are most commonly stained of the same ochreous colour as the flints of the gravel in which they are embedded. Occasionally their antiquity is indicated not only by their colour but by superficial incrustations of calcium carbonate, or by dendrites formed of oxide of iron and manganese (see figs. 73–75, p. 73). The edges also of most of them are worn, sometimes by having been used as tools, and sometimes by having been rolled in the old river's bed.

In addition to the flints which have evidently been chipped or ground, so as to form implements of very definite shape, others of a much ruder type are found, which Professor Prestwich and other geologists and archæologists regard as marking a still more primitive condition of the human race. The flints in question are simply flat, irregular fragments which have been picked up to serve the purpose of scrapers, and they bear on their edges the marks of having been so employed. The Tasmanians and some other savage tribes are known to employ fragments of flint or similar hard materials in this way, without

any attempt at fashioning them into tools. The rude flints of this type are found scattered over the plateaux of our chalk districts, or embedded in gravels in this situation. Concerning the artificial origin of the fractures on the edges of some of this rude plateau-type of flint implements, which have been called 'Eolithic' by some authors, doubt has, however, been expressed by many geologists and antiquaries.

Representatives of the Pleistocene deposits in Britain and the adjoining portions of Western Europe.—There is one very noteworthy distinction between the deposits of Pleistocene age and those which constitute the older geological systems. While the latter are almost entirely represented by subaqueous accumulations, and have, indeed, for the most part been laid down on the sea-bottom and subsequently elevated, the Pleistocene formations are largely of terrestrial or at least of lacustrine or fluviatile origin, and comprise deposits that have not been washed away during the subsidence of the land, like nearly all similar accumulations of greater antiquity.

We will proceed to consider the chief types of these Pleistocene deposits—terrestrial, fluviatile, lacustrine, fluviomarine, marine, and glacial, as they are represented in this country and the adjoining parts of Europe.

Among the terrestrial deposits of the Pleistocene we may call attention to the peat deposits which have yielded such valuable evidence concerning the events which took place in prehistoric times. These peat deposits have been especially studied in Denmark, and many monuments of the early inhabitants of that country have been brought to light by the combined labours of the antiquary, the zoologist, and the botanist.

The late geological age of these peat-mosses is demonstrated by the fact that not only the contemporaneous freshwater and land shells, but all the quadrupeds, found in the peat, agree specifically with those now inhabiting the same districts, or known to have been indigenous in Denmark within the memory of man. In the lower beds of peat (a deposit varying from 20 to 30 feet in thickness), weapons of stone accompany trunks of the Scotch fir, *Pinus sylvestris*, L. This peat may be referred to that part of the stone period known as 'Neolithic,' in contradistinction to a still older era, termed 'Palæolithic.' In the higher portions of the same Danish bogs, bronze implements are associated with trunks and acorns of the common oak. It appears that the pine has never been a native of Denmark in historical times, and it seems to have given place to the oak about the time when articles and instruments of bronze superseded those of stone. It also appears that, at a still later period, the oak itself became scarce, and was nearly supplanted by the beech, a tree which now flourishes luxuriantly in Denmark. Again, at the still later epoch when the beech-tree abounded, tools of iron were introduced, and were gradually substituted for those of bronze.

On the coasts of the Danish islands in the Baltic, certain mounds, called in those countries 'Kjökken-mödding,' or 'kitchen-middens,' occur, consisting chiefly of the castaway shells of the oyster, cockle, periwinkle, and other eatable kinds of mollusks. The mounds are from 3 to 10 feet high, and from 100 to 1,000 feet in their longest diameter. They greatly resemble the heaps of shells formed by the Red Indians of North America along the eastern shores of the United States. In the old refuse-heaps, recently studied by the Danish antiquaries and naturalists with great skill and diligence, no implements of metal have ever been detected. All the knives, hatchets, and other tools are of stone, horn, bone, or wood. With them are often intermixed fragments of rude pottery, charcoal, and cinders, and the bones of quadrupeds on which the early people fed. These bones belong to wild species still living in Europe, though some of them, like the beaver, have long been extirpated in Denmark. The only animal which they seem to have domesticated was the dog.

As there is an entire absence of metallic tools, these refuse-heaps are referred to the Neolithic division of the age of stone, which immediately preceded in Denmark the age of bronze. It appears that a race more advanced in civilisation, armed with weapons of that mixed metal, invaded Scandinavia and ousted the aborigines.

Cavern deposits containing human remains and bones of extinct animals.—In England, and in almost all countries where limestone rocks abound, caverns are found, usually consisting of cavities of large dimensions, connected with one another by low, narrow, and sometimes tortuous galleries or tunnels. These subterranean water-ways are usually filled in part with mud, pebbles, and breccia, in which bones may occur belonging to various animals. Some of these bones are referable to extinct and others to living species, and they are occasionally intermingled with implements of one or other of the great divisions of the stone age, and these are sometimes, though very rarely, accompanied by human bones.

Each suite of caverns, and the passages by which they communicate with one another, afford memorials to the geologist of successive phases through which they must have passed. First there was a period when the calcium carbonate was dissolved away gradually by drainage water containing carbon dioxide in solution; secondly, an era when engulfed rivers or occasional floods swept organic and inorganic *débris* into the subterranean hollows thus formed; and thirdly, a time when the formation of stalagmite took place on the floor, covering up the deposits.

The quarrying away of large masses of Carboniferous and Devonian limestone, near Liège, in Belgium, has afforded the geologist magnificent sections of some of these caverns, and the former communication of cavities in the interior of the rocks with the old surface of the country, by means of vertical or oblique fissures, has been demonstrated in places where it would not otherwise have been suspected—so completely have the upper extremities of these fissures been concealed by superficial drift, while their lower ends, which extended into the roofs of the caves, have been masked by stalactitic incrustations.

The origin of the stalactite has been noticed (p. 24), and it may

now be explained that it is when caverns have ceased to be in a line of active drainage, or to form underground conduits, that a solid floor of hard stalagmite is formed on the bottom.

The late Dr. Schmerling examined forty caves near Liège, and found in all of them the remains of the same fauna, comprising the Mammoth, Tichorhine Rhinoceros, Cave-bear, Cave-hyæna, Cave-lion, Reindeer, and many others—some of extinct and some of living species—and also flint-implements. In four or five caves only, parts of human skeletons were met with, comprising sometimes skulls with a few other bones, sometimes nearly every part of the skeleton except the skull. In one of the caves, that of Engihoul, where Schmerling had found the remains of at least three human individuals, they were mingled in such a manner with bones of extinct mammalia, as to leave no doubt in his mind of man having coexisted with them.

The careful investigations carried on by Falconer, Pengelly, and others, in the Brixham cave and at Kent's Cavern, near Torquay, afforded evidence that flint knives were embedded in red earth underlying a floor of stalagmite, in such a manner as to prove that man had been an inhabitant of that region, when the Cave-bear and other members of the ancient Pleistocene fauna were also in existence.

The following are the species which have been discovered in the English caves. Those which are extinct are *Elephas primigenius*, Blumenb., and *E. antiquus*, Falc., *Rhinoceros tichorhinus*, Cuv., *R. leptorhinus*, Cuv., *Machairodus latidens*, Ow., *Ursus spelæus*, Blumenb., *Cervus megaceros*, Hart., *C. Brownii*, Dawk., *Bison priscus*, Boj. The species still living in Africa are the Hippopotamus, Lion, and Hyæna. *Antilope* and *Felis pardis*, L. (Panther) are now Asiatic. Of species now living in North America we find the Grizzly Bear; and of those occurring in N. Europe, the Elk, Reindeer, Lemming, and Glutton. Besides these, there are found many of the commonest European species of mammalia.

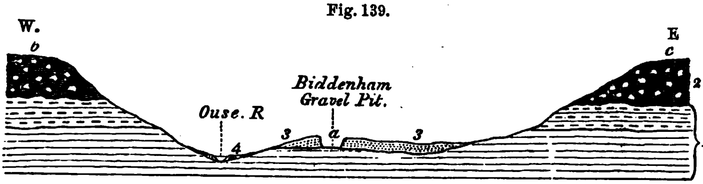
The absence of gnawed bones led Dr. Schmerling to infer that none of the Belgian caves which he explored had served as the dens of wild beasts; but there are many caves in Germany and England which have certainly been so inhabited, especially by the extinct Hyæna and Bear.

A fine example of a hyæna's den was afforded by the cave of Kirkdale, so well described by the late Dr. Buckland in his 'Reliquiæ Diluvianæ.' In that cave, above twenty-five miles NNE. of York, the remains of about 300 hyænas, belonging to individuals of every age, were detected. The species (*Hyæna spelæa*, Goldf.) has been considered by palæontologists as extinct; it was larger than the fierce *Hyæna crocuta*, Zimm., of South Africa, which it closely resembled, and of which it is regarded by Professor Boyd Dawkins as a variety. Dr. Buckland, after carefully examining the spot, proved that the hyænas must have lived there; a fact attested by the quantity of their dung, which, as in the case of the living hyæna, is of nearly the same composition as bone, and almost as durable. In the cave were found the remains of the Ox, Mammoth Hippopotamus, Rhinoceros, Horse, Bear, Wolf, Hare, Water-rat, and several birds. All the bones have the appearance of having been broken and gnawed by the teeth of the hyænas; and they occur confusedly

mixed in loam or mud, or dispersed through a crust of stalagmite which covers it. In these and many other cases it is supposed that portions of herbivorous quadrupeds have been dragged into caverns by beasts of prey, and have served as their food—an opinion quite consistent with the known habits of the living hyæna.

Alluvial deposits of the Palæolithic age.—The alluvial deposits of the Palæolithic age are the earliest in which any vestiges of man have yet been certainly detected, and they belong to a time

Fig. 139.



Section across the Valley of the Ouse, two miles WNW. of Bedford.

1. Oolitic strata.
2. Boulder clay, or marine northern drift, rising to about ninety feet above the Ouse.
3. Ancient gravel, with elephant bones, freshwater shells, and flint implements.
4. Modern alluvium of the Ouse.

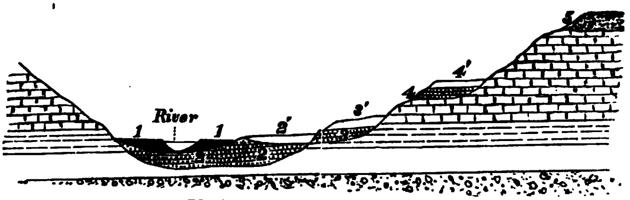
a. Biddenham gravel pit, at the bottom of which flint tools were found.

when the physical geography of Europe differed in a marked degree from that now prevailing. Since those deposits originated, changes of considerable magnitude have been effected in the depth and width of many valleys, as also in the direction of the superficial and subterranean drainage, and, as is manifest near the sea-coast, in the relative position of land and water.

In the above diagram (fig. 139) is shown the relative position which the gravel, containing flint implements and the bones of extinct animals, bears to the older formations, out of which the valley has been formed. In fig. 140, a similar but ideal section is given, illustrating the different positions which the Pleistocene alluvial deposits occupy in many European valleys.

The peat No. 1 (fig. 140) has been formed in a low part of the modern alluvial plain, in parts of which gravel No. 2 of the recent period is seen. Over this gravel the loam or fine sediment 2′ has in

Fig. 140.



Ideal section across a river valley.

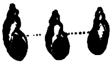
many places been deposited by the river during floods which covered nearly the whole alluvial plain.

No. 3 represents an older alluvium, composed of sand and gravel,

formed before the valley had been excavated to its present depth. It contains the remains of fluviatile shells of living species associated with the bones of mammalia, in part of recent, and in part of extinct species. Among the latter, the Mammoth (*Elephas primigenius*, Blumenb.) and the Hairy Rhinoceros (*R. tichorhinus*, Cuv.) are common. No. 3′ is a remnant of the loam or brick earth by which No. 3 was overspread. No. 4 is a still older and more elevated terrace, similar in its composition to No. 3, and covered in like manner with its inundation mud (4′). Sometimes some or all of the valley gravels of older date are missing. They usually occur at heights, above the present stream, varying from 10 to 300 feet, sometimes on the right, and sometimes on the left, side of and usually on exactly opposite sides of the valley. The upper deposit (5) is the gravel of the plateaux; 4 is termed High-level, and 3 Low-level, gravel.

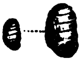
Among the genera of quadrupeds most frequently met with in England, France, and Germany, the commonest remains in the high- and low-level river gravels (4 and 3) are, in England, the Mammoth, Ancient Elephant (*E. antiquus*, Falc.), Hairy Rhinoceros, Leptorhine Rhinoceros, Horse, Boar, Great Hippopotamus, Bison, Primitive Ox (*Bos primigenius*, Boj.), Musk Ox, Reindeer, Irish Elk, Red Deer, Cave Lion, Cave Hyæna, Wolf, Grizzly Bear, and Otter. Some of these kinds of animals are extinct, others inhabit Africa and Asia, whilst some are only found within the Arctic circle. Two are N. American. A few kinds still exist on the area. In the peat (No. 1) and in the more modern gravel and silt (No. 2), works of art

Fig. 141.



Succinea oblonga (Drap.), nat. size.

Fig. 142.



Pupa muscorum (Müll.), nat. size.

Fig. 143.

Helix hispida (Müll.), nat. size.

of the ages of iron and bronze, and of the later or Neolithic stone period, already described, are met with. In the more ancient gravels (3 and 4), there have been found in several valleys in France and England—as, for example, in those of the Seine and Somme, and of the Thames and Ouse, near Bedford—stone implements of a rude type, termed 'Palæolithic,' showing that man coexisted in those districts with the Mammoth and other extinct quadrupeds of the genera above enumerated.

The loam or brick-earth of our English river-valleys presents many points of analogy with the 'loess' of the Rhine and other European rivers.

Although this loess of the Rhine is unsolidified, it usually terminates, where it has been undermined by running water, in a vertical cliff, from the face of which shells of terrestrial, freshwater, and amphibious molluscs project in relief. These shells do not imply the permanent sojourn of a body of fresh water on the spot, for the most aquatic of them, the *Succinea*, inhabits marshes and wet grassy meadows. The *Succinea oblonga*, Drap. (fig. 141), is very characteristic both of the loess of the Rhine and of some other European river-loams.

Among the land-shells of the Rhenish loess, *Helix hispida*, Müll.,

fig. 143, and *Pupa muscorum*, L., fig. 142, are very common. Both the terrestrial and aquatic shells are of most fragile and delicate structure, and yet they are almost invariably perfect and uninjured. They must have been broken to pieces had they been swept along by a violent inundation. Even the colour of some of the land-shells, as that of *Helix nemoralis*, Müll., is occasionally preserved.

In parts of the valley of the Rhine, between Bingen and Basle, the fluviatile loam or loess now under consideration is several hundred feet thick, and contains here and there throughout that thickness land and freshwater shells. As it occurs in masses fringing both sides of the great plain, and as, occasionally, remnants of it are found on eminences in the centre of the valley, and also forming hills several hundred feet in height, it seems necessary to suppose, first, a time when it slowly accumulated; and secondly, a later period, when large portions of it were removed—that is to say, when the original valley, which had been partially filled up with it, was re-excavated. The greatest altitude of the loess is at Fribourg (284 mètres).

Such changes may have been brought about by a great movement of oscillation, consisting of a general depression of the land, followed by a gradual re-elevation of the same. The amount of continental depression which first took place in the interior must be imagined to have exceeded that of the region near the sea, in which case the higher part of the great valley would have its alluvial plain gradually raised by an accumulation of sediment, which would only cease when the subsidence of the land was at an end. If the direction of the movement were then reversed, and, during the re-elevation of the continent, the inland region nearest the mountains rose more rapidly than that near the coast, the river would acquire a denuding power sufficient to enable it to sweep away, gradually, much of the loess with which parts of its basin had been filled up. Terraces and hillocks of mud and sand would then alone remain to attest the various levels at which the river had thrown down and afterwards removed alluvial matter.

High plateau-gravels and loess.—These are spread far and wide (see fig. 140, No. 5), and are sometimes very distinct in their character and at other times merge gradually into soil above and the parent rock below. In the first instance they often contain rock-fragments brought from a distance, and this and the circumstance that they cover up equally strata of many kinds are only explicable by the area of deposit having been at one time below slowly drifting water. It is in these deposits that the very rudely worked flints, described by Professor Prestwich, have been found.

Inundation-mud of rivers.—Brick-earth.—Fluviatile loam, or loess.—As a general rule, the fluviatile alluvia of different ages (Nos. 2, 3, 4, fig. 140, p. 161) are severally made up of coarse materials in their lower portions, and of fine silt or loam in their upper parts. For rivers are constantly shifting their position in the valley-plain, encroaching gradually on one bank, near which there is deep water, and deserting the other or opposite side, where the channel is growing shallower, being destined eventually to be converted into land. Where the current runs strongest, coarse gravel is swept along, and where its velocity is slackened, first sand, and then only the finest mud, is thrown down. A thin film of this fine sediment is spread, during floods, over a wide area, on one, or sometimes

on both sides, of the main stream, often reaching as far as the base of the bluffs or higher grounds which bound the valley. Of such a description are the well-known annual deposits of the Nile, to which Egypt owes its fertility. So thin are they, that the aggregate amount accumulated in a century is said rarely to exceed five inches, although in the course of thousands of years it has attained a vast thickness, the bottom not having been reached by borings extending to a depth of 143 feet towards the central parts of the valley. Everywhere it consists of the same homogeneous mud, destitute of stratification—the only signs of successive accumulation being where the Nile has silted up its channel, or where the blown sands of the Libyan desert have invaded the plain and given rise to alternate layers of sand and mud.

In European river-loams we occasionally observe isolated pebbles and angular pieces of stone which have been floated by ice to the places where they now occur; but no such transported blocks are met with in the plains of Egypt.

In some parts of the valley of the Rhine, as we have already seen, the accumulation of similar loam, called in Germany 'loess,' or 'lehm,' has taken place on an enormous scale. Its colour is yellowish grey or reddish, and it is very homogeneous. Although for the most part unstratified, it betrays in some places marks of stratification, especially where it contains calcareous concretions, or in its lower part where it rests on subjacent gravel and sand, which alternate with each other near the junction. By the same name of 'loess,' geologists also frequently distinguish great masses of fine yellow sandy clay which cover vast areas in Central Asia and other districts. The accumulation of these deposits in Northern China, where they are often of vast thickness, has been referred by Richthofen to the action of wind; but other muds of similar character are not improbably of subaqueous origin.

Lacustrine deposits.—The lacustrine deposits of the Pleistocene period consist of silt and shelly marl, sometimes alternating with beds of peat which occupy the sites of old lakes now filled up. The freshwater shells and plants found fossil in these strata usually belong to living species, but with these occur the remains of many mammalia now living in Europe, with others like the great Irish elk (*Cervus megaceros*, Hart.), which is now extinct. In some of these lacustrine deposits the remains of man occur, especially in connection with the ruins of dwelling-places built on piles (*Pfahlbauten*), which have been found in Switzerland and other countries.

Estuarine deposits.—Fluvio-marine or estuarine deposits of Pleistocene age have been found at the mouths of many of the British rivers—as the Clyde, Forth, and Humber. In these, the shells and bones of marine organisms are not unfrequently mingled with tusks and teeth of land animals, such as elephant, hippopotamus, elk, deer, ox, horse, hyæna, &c., while in the more superficial and younger parts of these accumulations canoes, hollowed out of trunks of trees by the aid of fire, have in some instances been detected in association with Palæolithic stone implements.

Marine deposits.—The fluvio-marine deposits graduate insensibly into those of purely marine character. Among these we may notice the raised sea-beaches which are found along many of the deep inlets (firths) or sheltered bays in the British Islands at heights of about 25, 50, 100 feet, and, more obscurely, at still greater ele-

vations. In other countries such raised beaches can be seen at much greater heights above the sea. Darwin traced them on the west coast of South America up to elevations of 1,300 feet above the sea-level, though human remains were only found in them up to a height of 85 feet, and shells up to a height of 625 feet.[2] It is only in the lower portions of these that remains of human handiwork have been found, but it must always be remembered that, as Darwin pointed out, the passage of atmospheric waters through masses of loose material upon the land will tend to the obliteration alike of the traces of organisms or articles of human workmanship.

The beds of peat, often containing trunks of trees, which are found below the present sea-level, and are occasionally exposed during low tides, are known as 'submerged forests.' They are often covered by strata of shingle, sand, or silt, and are only seen when these latter have been scoured away by the action of the waves. They sometimes yield many plant remains (leaves, seeds, and fruits), with the wings and wing-cases of insects, sometimes preserved in amber, and the bones and teeth of recent or extinct mammalia.

On the other hand, we frequently find, as in the West Indies, Florida, the Solomon Islands, &c., great masses of coral rock and of deep-sea deposits, like the globigerina and radiolarian oozes, at elevations up to and even exceeding 1,000 feet above the sea-level.

Subdivisions of the Pleistocene deposits.—In attempting to make out a chronological sequence among the various Pleistocene deposits, we are aided by the circumstance that, in Europe and North America alike, we find clear evidence of a remarkable episode—namely, the setting in for a time of a period of intense cold. According to the calculations of Professor Bonney, a lowering of the mean annual temperature of Western Europe and Eastern North America by 16° to 18° F. would be required to produce the results of which we find such abundant evidence.

The Glacial Period.—Over a great part of Europe north of the 50th, and of North America north of the 39th parallel of latitude, we find vast masses of loose transported materials, lying indifferently upon all the older formations, and evidently made up of fragments derived from them.

These deposits consist of sand and clay, containing a mixture of angular and rounded fragments of rock, of which some may be of large size. It is often wholly devoid of stratification for a depth of 50, 100, or even a greater number of feet, and is occasionally found stratified, especially in the higher parts of the series of deposits, and where sandy beds occur with marine organisms. To the unstratified form of the deposit the name of *till* has long been applied in Scotland, while its argillaceous representative is known in England as 'boulder clay.' The included stones often have one or more of their sides flattened and smoothed, or even highly polished, the smoothed surfaces usually exhibiting many parallel scratches, one set often crossing an older set. The till is almost everywhere devoid of

[2] Darwin's *Geological Observations on South America*, chap. ii.

organic remains, except those washed into it from older formations, but in a few localities it contains marine shells, usually of northern or Arctic species, and nearly always in a very fragmentary state. The bulk of the till has usually been derived from the grinding down into mud of rocks in the immediate neighbourhood, so that it is red in a region of Red Sandstone, as in Strathmore in Forfarshire; grey or black in a district of coal and bituminous shale, as around Edinburgh; and white in a chalk country, as in parts of Norfolk and Denmark. The stony fragments dispersed irregularly through the till usually belong, especially in mountainous countries, to rocks found in some part of the same hydrographical basin. But there are regions where the whole of the boulder clay has come from a distance, and huge blocks, or 'erratics,' as they have been called, many feet in diameter, have not unfrequently travelled scores or even hundreds of miles from their point of departure, or from the parent rocks from which they have evidently been detached, and have crossed over the water-partings between the valleys. These stones are commonly angular, and have often one or more of their sides polished and furrowed.

The rock on which the boulder formation reposes, if it consists of granite, gneiss, limestone, or other hard material, capable of permanently retaining any superficial markings which may have been imprinted upon it, is usually smoothed or polished, like the erratics above described (see fig. 144). It exhibits parallel striæ and furrows having a determinate direction. Such striæ are found at great elevations, even up to 3,000 feet in the Scottish Highlands. The direction, both in Europe and North America, agrees generally in a marked manner with the course taken by the erratic blocks in the same district.

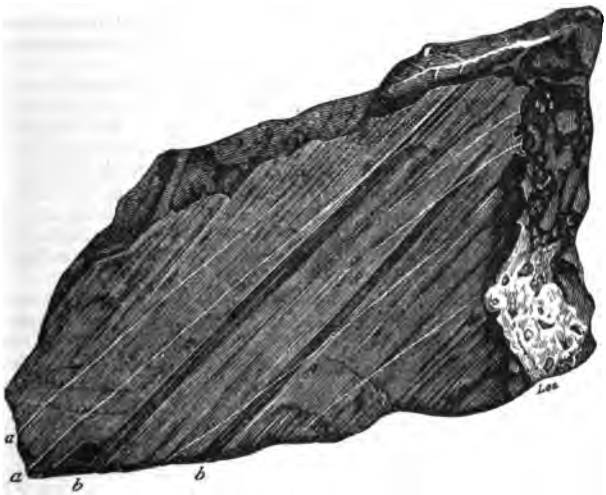
Another form of glacial drift consists of beds of gravel and sand, which usually rest on the boulder clay when the two formations occur together. It is probable that the bulk of this drift had the same origin as the till and boulder clay, but that subsequently the clay and sand have been washed out, and the stones and gravel spread out by currents of water are so worn that they rarely show scratches and polished surfaces. Like the boulder clay, this gravel rarely contains fossils, and when these do occur they are generally fragmentary and much waterworn.

The boulder clay, when it was first studied, seemed in many of its characters so singular and anomalous, that geologists despaired of ever being able to interpret the phenomena by reference to causes now in action. In those exceptional cases, where marine shells of the same date as the boulder clay were found, nearly all of them were recognised as living species, but now flourishing in Arctic latitudes—facts conspiring with the superficial position of the drift to indicate a comparatively modern origin and a great change in climate.

The term 'diluvium' was for a time the popular name of the boulder formation, because it was referred, by many, to the deluge of Noah, while others retained the name as expressive of their opinion that a series of diluvial waves—raised by hurricanes and storms, or by earthquakes, or by the sudden upheaval of land from the bed of the sea—had swept over the continents, carrying with them vast masses of mud and heavy stones, and forcing these stones over rocky surfaces so as to polish and imprint upon them long

furrows and striæ. But geologists were not long in seeing that the boulder formation was characteristic of high latitudes, and that on the whole the size and number of erratic blocks increase as we travel towards the Arctic regions. They could not fail to be struck with the contrast which the countries bordering the Baltic presented, when compared with those surrounding the Mediterranean. The multitude of travelled blocks and striated rocks in the one region, and the absence of such appearances in the other, were too obvious

Fig. 144.



Limestone, polished, furrowed, and scratched by the glacier of Rosenlaui in Switzerland. (Agassiz.)

a a. White streaks or scratches, caused by small grains of flint frozen into the ice.
b b. Furrows.

to be overlooked. When the nature of glaciers, their movements, denuding and transporting powers were first studied, it was supposed that the terminal moraines, or the collections of mud and angular stones at the foot of the glacier, were analogous to boulder clay. This is not the case, but it is probable that where the glaciers terminate in the sea, as they do in the Arctic regions in many places, the moraine matter may assume many of the characters of boulder clay. During the last North-Polar expedition, an unctuous clay was frequently found covering the sea floor near glaciers. Some authors maintain that a deposit similar to boulder clay may accumulate underneath glaciers, but of the existence of such a *moraine profonde*, as it has been called, no very satisfactory proofs have been adduced.

Similar traces of glacial action to those now found in the higher mountain chains—as smoothed and striated rock surfaces, often forming 'roches moutonnées, heaps of moraine matter (sometimes damming up the ends of lakes), perched and erratic blocks—are found in all the higher portions of the British Islands, North Wales, the

Lake District, the Scottish Highlands, and also on the more elevated ground in Ireland. Attention was first called to the occurrence of these traces of ancient glaciers in our own island by Agassiz in 1840; and since his time the labours of Darwin, Buckland, Ramsay, the brothers Geikie, and many others have greatly strengthened the conclusions which the great Swiss naturalist drew from their occurrence as to the existence of a glacial epoch during Pleistocene times. While these relics of glaciers exist in the higher grounds, the lower lands of Britain, as far south as the valley of the Thames, exhibit great masses of boulder clay, sometimes alternating with sands, which are occasionally finely laminated and at other times much contorted (see fig. 11, p. 41); erratic blocks are found even as far south as the Thames Valley.

Not unfrequently, in the glacial sands, and occasionally in the boulder clay itself, we find shells of marine mollusca usually belonging to species which now flourish in the Arctic seas. Such deposits of sand with Arctic shells have been found at Airdrie in Scotland up to elevations of 524 feet above the sea, at Three-Rock Mountain, and other localities in Dublin and Wexford, Ireland, up to 1,000 or 1,200 feet above the sea; at Mottram, east of Manchester, at 568 feet, at Vale Royal, near Macclesfield, between 1,100 and 1,200 feet, at Gloppa, Cheshire, at 1,200 feet, and at Moel Tryfaen in North Wales at over 1,300 feet above that level.

By many geologists, the occurrence of these marine shells at such great elevations is accepted as evidence of great submergence during the Pleistocene period. Others, however, considering the very fragmentary condition and local occurrence of these shells, the fact that in the same band we find species that live at very different depths, and the other circumstances of their occurrence, maintain they may have been brought into their present elevated condition by the action of great glaciers or ice-sheets pushing up portions of the sea-floor, possibly in a frozen condition, to the hill slopes on which we now find them.

Bridlington drift.—The so-called crag at Bridlington, containing many mollusca of Arctic kinds, appears to be a portion of an old glacial deposit which has been torn up by stranding ice and embedded in boulder clay.

Erratics near Chichester.—The most southern memorials of ice-action and of a Pleistocene fauna in Great Britain are found on the coast of Sussex. A marine deposit exposed between high and low tide occurs on both sides of the promontory called Selsea Bill, in which Mr. Godwin-Austen found thirty-eight species of shells, and the number has since been raised to a hundred and forty. These erratics and shells were probably brought by ice floating in the English Channel of those days.

This assemblage is interesting because, while all the species are recent, they have on the whole a somewhat more southern aspect than those of the present British Channel. What renders this curious is the fact that the sandy loam in which they occur is overlaid by yellow clayey gravel with large erratic blocks which must have been drifted into their present position by ice when the climate had become much colder. These transported fragments of granite and greenstone, as well as of Devonian and Silurian rocks, may have come from the coast of Normandy and Brittany, and are many of

them of such large size that we must suppose them to have been drifted into their present site by coast-ice.

Connection of the predominance of Lakes with glacial action.—Generally, when the winter cold is intense, as in Canada, Scandinavia, and Finland, even the plains and lowlands are thickly strewn with innumerable ponds and small lakes, together with some of larger size; while in more temperate regions, such as Great Britain, Central and Southern Europe, the United States, and New Zealand, lake-districts occur in all such mountainous tracts as can be proved to have been glaciated in times comparatively modern, or since the geographical configuration of the surface bore a considerable resemblance to that now prevailing. In the same countries lakes abruptly cease beyond the glaciated regions.

A large proportion of the smaller lakes are dammed up at their lower end by barriers of unstratified drift, having the exact character of the moraines of glaciers, and are termed by geologists 'morainic,' but a few of them are true rock-basins and would hold water even if all the loose drift now resting on their margins were removed.

The late Sir Andrew Ramsay maintained that all the rock-basins now occupied by lakes, both great and small, were actually excavated by the glaciers which once occupied their beds. Most geologists, however, are now agreed that while the occupation of such rock-basins by ice for long periods of time may have retarded the work of filling them up by sediments, the rock-basins must themselves be regarded as due to differential movements in the earth's crust along lines of drainage. The study by Gilbert, Spencer, and others of the great lake-basins of the northern and western parts of the North American continent, and of the alterations which have been effected in the levels of the old beaches which surround them, has afforded remarkable confirmations of these views.

One of the most serious objections to the exclusive origin by ice-erosion of wide and deep lake-basins arises from their capricious distribution; thus, for example, in Piedmont, both to the eastward and westward of Turin, great lakes are wanting, although some of the largest extinct glaciers descending from Mont Blanc and Monte Rosa came down from the Alps, leaving their gigantic moraines in the low country. Here, therefore, we might have expected to find lakes of the first magnitude rivalling the contiguous Lago Maggiore in importance.

A still more striking illustration of the same absence of lakes where large glaciers abound is said to be afforded by the Caucasus, whose loftiest peaks attain heights from 16,000 to 18,000 feet. The present glaciers of this mountain chain are equal or superior in dimensions to those of Switzerland, yet it is remarked by Mr. Freshfield that 'a total absence of lakes, on both sides of the chains, is the most marked feature. Not only are there no great subalpine sheets of water, like Como or Geneva, but mountain tarns, such as the Dauben See, on the Gemmi, or the Klonthal See, near Glarus, are equally wanting.' The Himalayas also are singularly free from lakes.

Lakes contain a remarkable fauna; the crustacea have marine affinities, and in some lakes there are seals which cannot have passed in by the existing rivers. The great North American lakes have submerged cañons on their floors. The grander lakes are old areas of denudation, depressed or raised above sea-level by earth move-

ments. They were not formed during the glacial epoch, but long before that period, though their forms may have been greatly modified both during and since glacial times.

The subdivision of the great system of strata constituting the Pleistocene period is facilitated, as we have seen, by the occurrence of the glacial episode. The epoch which preceded the coming in of the intense cold we call the *pre*-glacial, and during this time we find many evidences of a gradual refrigeration, which probably commenced before the end of the Pliocene. Some observers have thought not only that they could detect proofs that there was a gradual increment and decrement of cold during the earlier and later stages of the glacial epoch, but that evidence of one or more intervals of marked amelioration in the severity of the climate can be traced in studying the deposits. These intervals of less intense cold, or, according to some observers, of moderately warm climate, have been called interglacial periods.

The *post*-glacial division of time was marked in its earlier portion by considerable rigour of climate, and possibly an abundant rainfall. During this epoch much of the soil may have remained frozen to a great depth, and the rivers appear to have been more swollen and torrential in their character. To this epoch the late Mr. A. Tylor proposed to apply the name of 'the pluvial period.' It probably corresponds approximately to the Champlain period of North America.

In favour of the use of the terms 'recent' period and 'human' period there is, as already pointed out, little to be said. But both archæologists and geologists find it useful to distinguish the several epochs at which implements of human workmanship, showing different stages in civilisation, were employed. Setting aside the very doubtful alleged discoveries of objects of human workmanship in Pliocene and Miocene formations, we have some very rude implements found in very high-level (plateau) gravels in the south of England. If the artificial origin of these be established beyond doubt by further research, they probably constitute the oldest known relics of man—or of tool-making animals—upon the globe. The oldest undisputed types of implements, those figured on p. 156 as occurring in the valley-gravels and cavern-deposits are known as Palæolithic, and the more carefully finished instruments occurring in France in association with remains of the reindeer are known as Newer Palæolithic. The Older and Newer Palæolithic are sometimes distinguished as the Age of the Mammoth and Reindeer respectively. The epoch at which more carefully finished, and often polished, stone implements were employed is known as Neo-

lithic; and then follow the Copper Age (of certain areas), the Bronze Age, and the Iron Age.

This classification of epochs by the aid of the works of art which characterise them is of use to the archæologist, however, rather than to the geologist. It is still uncertain if the so-called 'human' period began after the Glacial, or overlaps, as some observers think, the Glacial and even the Pre-glacial. On the other hand, it is clear that the several ages of stone and metal implements belong to very distinct periods of time in different countries. Some savage races have not, even at the present day, advanced beyond their 'stone age.'

For fuller details concerning the Pleistocene deposits, the student is referred to Professor Dawkins's 'Cave and Cave Hunting,' to Professor James Geikie's 'Great Ice Age' (3rd ed. 1895) and 'Pre-historic Europe,' and to Professor Wright's 'Man and the Glacial Period.' On the earliest relics of the human race, he may consult Lyell's 'Antiquity of Man,' Professor Prestwich's papers on the river-gravels of the North of France and the South-east of England, and Sir John Evans's 'Ancient Stone Implements, Weapons, and Ornaments of Great Britain.' Professor Prestwich's 'Essays on Controverted Questions in Geology,' 1895, furnishes an account of the so-called 'Eolithic' remains.

CHAPTER XIII

THE NEWER-TERTIARY STRATA (NEOGENE OR NEOCENE)

Use of the Terms Miocene and Pliocene, Neogene and Neocene—Mollusca of the Newer-Tertiary Strata—Mammalia of the Newer Tertiaries—The Newer-Tertiary Flora—British Newer and Older Pliocene Strata—Forest-bed of Cromer—Chillesford and Aldeby beds—Red Crag—White or 'Coralline' Crag—Older Pliocene deposits of the North Downs and of St. Erth—Relation of the Fauna of the Crag to that of the present day—Proofs of denudation between the periods of deposition of the British Older and Newer Tertiaries.

Nomenclature and Classification of the Newer-Tertiary strata.—The principle on which the original classification of the Tertiary strata was based has been explained in a previous chapter. Experience, however, has shown that, valuable as is this classification for many purposes, a grouping of the Lyellian subdivisions is necessary to form systems of strata comparable to the great divisions of the Mesozoic and Palæozoic rocks. Alike in Eastern Europe and in Western North America, it has been found impracticable to separate the Pliocene and the Miocene as well-defined systems of strata; and hence they have been united as characterising one great period of the earth's history called by the Vienna geologists the 'Neogene,' and by the American geologists the 'Neocene.' A twofold division of the

Tertiary strata in this country has long been in use, the names applied to the two portions being 'Older Tertiary' and 'Newer Tertiary' respectively. We shall, therefore, in the present work treat the Tertiary strata which underlie the Pleistocene as forming two great systems—the Newer Tertiary, of which the Pliocene and Miocene constitute the main divisions, and the Older Tertiary, including not only the Eocene of Lyell but also the strata overlying it, which are known as Oligocene, and those underlying it, which have been called the Paleocene.

The Miocene, which is so well represented in the south-west of France (the Faluns of Touraine), is sometimes called the Falunian. In Switzerland the strata of this age are known as the Molasse. The Pliocene strata attain a great thickness and importance in Italy along the flanks of the Apennines, and are hence often called the Sub-apennine strata. In Eastern Europe the Miocene and Pliocene, as we have seen, form one great series, which is called the Neogene; and the same is the case in the United States, where they are called Neocene.

Of the two great divisions of the Newer-Tertiary strata, the Miocene and the Pliocene, only the latter has any representatives in the British Islands; and the thin and scattered patches of shelly sand called 'crag' occurring in East Anglia constitute a very insignificant representative of the Pliocene strata of Italy and Eastern Europe, which attain a thickness of many hundreds or even thousands of feet. In Belgium, too, we find a more complete representation of the Pliocene strata than in our own country.

The Pliocene or 'Crag' strata of East Anglia consist of the following members, beginning with the highest bed:—

The Forest-bed series, with many plant remains and bones and teeth of terrestrial mammalia.

The Chillesford sands and clays with a Molluscan fauna, containing only a few extinct forms, but with a proportion of over 60 per cent. of these belonging to Northern types.

The Norwich (or Fluvio-marine) Crag, containing an admixture of marine and freshwater shells and some Mammalian remains. Of the shells 93 per cent. are living forms, 14·6 per cent. being Northern types.

The Red Crag, consisting of shelly sands with 93 per cent. of living forms, of which 10·7 per cent. are Northern types.

The White ('Coralline')[3] Crag, formed of sands with argillaceous bands containing Mollusca and Bryozoa. Of the former 54 per cent. are living forms, and only 5 per cent. are Northern species.

[3] The term 'Coralline' was erroneously applied to the Bryozoa, which occur in such profuse abundance in these beds.

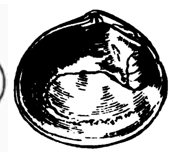
Characteristics of the fauna and flora of the Newer-Tertiary strata.—While in the Pleistocene strata all the mollusca belong to living species, the Newer-Tertiary beds contain, side by side with those recent forms of life, many others which have never been found in the existing seas; and such species must be presumed to have become extinct. In the younger (Pliocene) strata the proportion of these extinct species of shells is usually less than that of the living forms, while in the older (Miocene) beds the extinct forms are more numerous than the living ones.

As examples of living forms of mollusca found in the Newer Tertiaries, we may cite the bivalves and univalves represented below (figs. 145–148).

Fig. 145.

Nucula Cobboldiæ, Sow. ,nat. size.

Fig. 146.



Tellina obliqua, Sow., ½ nat.

Fig. 147.

Trophon antiquum, Müll. (*Fusus contrarius*, Sow.), ½ nat. size.

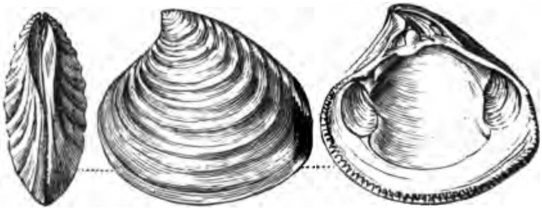
Fig. 148.

Purpura tetragona, Sow., nat. size.

It is noteworthy that the shell *Trophon antiquum*, Müll. (fig. 147), is in the existing seas almost always represented by ordinary or right-handed forms, while the opposite is found to be the case in the Neocene strata, where reversed or left-handed forms are much more common than the normal right-handed forms.

As examples of Neocene shells, now extinct, we may take the following common forms (figs. 149–154).

Fig. 149.



Astarte Omalii, Laj., nat. size; species common to Upper and Lower Crag.

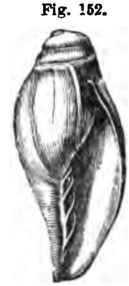
Fig. 150.

Voluta Lamberti, Sow., ½ nat. Variety characteristic of Faluns of Touraine. Miocene.

Fig. 151.

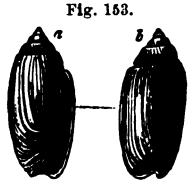
Voluta Lamberti, Sow., ½ nat. Variety characteristic of Suffolk Crag. Pliocene.

Fig. 152.



Voluta Lamberti, Sow., young individual, Cor. and Red Crag.

Fig. 153.



Oliva flammulata, Lam. Mio-pliocene of Belgium, nat. size. *a.* front view; *b.* back view.

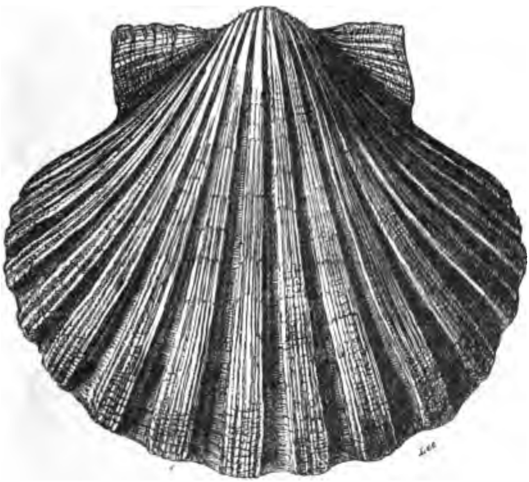
Fig. 154.

Murex vaginatus, Jan. Miocene.

The case of *Voluta Lamberti*, Sow., is interesting as showing that a species has sometimes undergone very marked varietal changes during the long periods of time covered by the Neozoic.

The Neocene mollusca—if studied in any particular area, like Britain, Italy, or the United States—seem to indicate the existence of a climate somewhat warmer than that of the seas

Fig. 155.



Pecten Jacobæus, L., ½ nat.

of the area at the present day; thus we find many tropical or sub-tropical forms like *Cypræa*, *Oliva*, *Murex*, &c., in the strata of Britain, France, and Belgium. Nevertheless, there is often a marked relation between the Pliocene, and to a less extent the Miocene, shells in a particular area and those living in the neighbouring seas at the present day.

Thus *Pecten Jacobæus*, L. (fig. 155), which is abundant in the Pliocene (Sub-apennine) strata of Italy, is still found living in the Mediterranean.

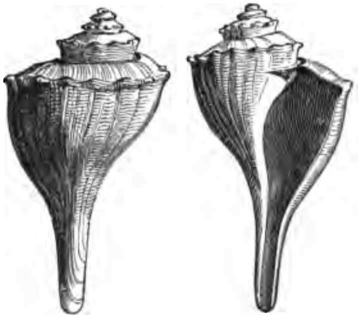
In the same way, we find some of the forms most abundant in the Newer Tertiaries of the Atlantic States of North America still living on the western shores of the Atlantic (see figs. 156, 157).

Occasionally shells which were at first supposed to be extinct have been afterwards detected in the existing seas; of this the shell *Natica helicoides*, Johnst. (fig. 158), is an example.

Many forms of Corals, Echinodermata, &c., very similar to those of the existing seas, abounded during this period.

Foraminifera are very numerous in some of the Miocene

Fig. 156.



Fulgur canaliculatus, L., sp., ½ nat. Maryland.

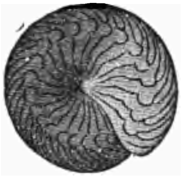
Fig. 157.

Fusus quadricostatus, Say, ½ nat. Maryland.

Fig. 158.

Natica helicoides. Johnst., nat. size.

Fig. 159.



Amphistegina Hauerina, D'Orb. Upper Miocene strata, Vienna; mag. 10 diams.

deposits; forms of *Nummulina* and of the closely allied *Amphistegina* still occurring, though in smaller numbers than in the Eocene.

Among the Newer-Tertiary strata, freshwater and terrestrial deposits are less commonly preserved than in the case of the Pleistocene; but they are so abundant and contain such well-preserved fossils that our knowledge of the plants, insects, and terrestrial vertebrates of the period is considerable.

The land-mammalia of the Pliocene are very different from those of the Pleistocene and of the present day. Elephants appear towards the close of the period, but the great group of the Proboscidians is generally represented by the extinct *Mastodon* and *Dinotherium*.

The Mastodons which occur in the Miocene pass up into the Pliocene, and in North America occur even in Pleistocene strata;

Fig. 160.

Mastodon arvernensis, Croiz. et Job., third milk molar, left side, upper jaw; grinding surface, natural size. Norwich Crag, Postwick; also found in Red Crag, see p. 187.

the molar teeth of the *Mastodon* (fig. 160) are less specialised than those of the Elephant, and some of the forms had incisors (tusks) in both upper and lower jaws. The *Dinotherium* (fig. 161), with tusks in the lower jaw, had still less specialised molar teeth than the Mastodons and Elephants, and are found only in Newer-Tertiary strata.

Fig. 161.

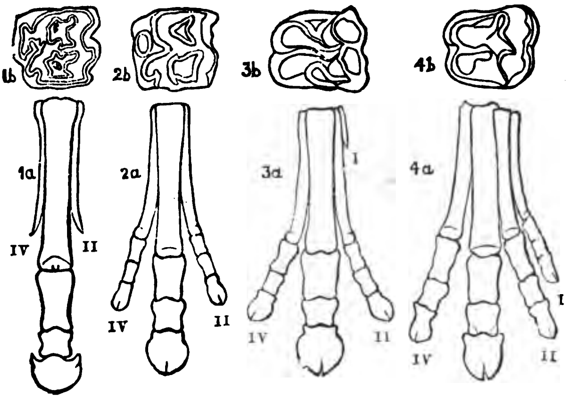
Dinotherium giganteum, Kaup. $\frac{1}{28}$ nat.

Remarkable and less specialised ancestors of the horse are found in the Newer Tertiaries in the *Hippotherium* or *Hipparion* of the Pliocene and the *Anchitherium* of the Miocene. And these were preceded by the still more generalised type *Orohippus* (*Hyracotherium*) of the Eocene (see fig. 162).

Other Newer-Tertiary mammals appear similarly to represent ancestral forms of the rhinoceros, hippopotamus, and camel. In the Sivâlik Hills in the North of India, at Pikermi in Greece, and in the island of Samos, remarkable forms allied to the giraffes have been found (*Helladotherium*, *Camelopardalis*, *Sivatherium* (fig. 163), *Sa-*

motherium (fig. 164, &c.), as well as curious types which appear to be links between the existing goats and antelopes.

Fig. 162.



Illustrations of the Ancestry of the Horse (*Equus caballus*, L.), after Marsh.

1a. Shows the highly specialised fore-foot of the horse, with a single fully developed digit, and others reduced to rudimentary 'splint-bones.'
1b. An upper molar of the horse, with its complicated pattern of enamel.
2a. Fore-foot of *Hipparion* from the Pliocene, with lateral digits more fully developed.
2b. Upper molar of *Hipparion*, showing simpler pattern of enamel.
3a. Fore-foot of *Anchitherium* from the Miocene, with fuller development of three digits.
3b. Upper molar of *Anchitherium*, with still simpler pattern of enamel.
4a. Fore-foot of *Orohippus* (*Hyracotherium*) from the Eocene, in which four digits are present.
4b. Upper molar of *Orohippus*, with still simpler arrangement of the enamel.

Deer, antelopes, oxen, sheep, and pigs are all represented in Newer-Tertiary times by many peculiar forms now extinct; insectivores, rodents, and true apes are also found. The Carnivores are represented by types related to, but very different in many of the details of their structure from, the hyænas, dogs, and bears of the present day.

We thus see that the Newer Tertiaries include many forms of mammalia which are distinctly less specialised than those of the present day, but do not exhibit the striking generalised characters which we shall find to be so characteristic of the Eocene types.

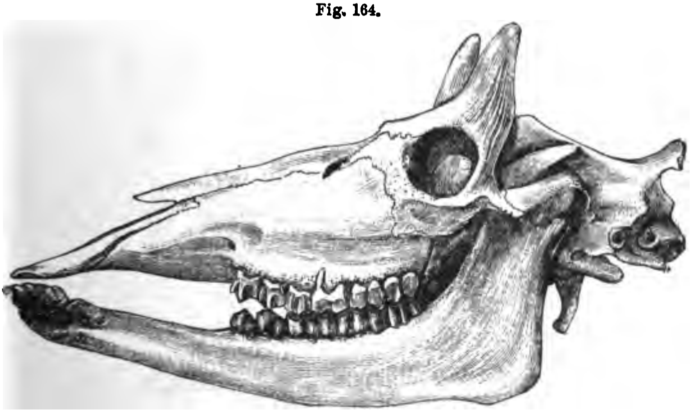
The Newer-Tertiary flora is a very rich one, and has been carefully studied by Heer and other botanists at Oeningen, near Schaffhausen, in Switzerland, and other localities, where leaves, fruit, and even flowers are often extremely well preserved in the

fine calcareous mud now indurated into a finely laminated stone. Many of the common European trees are represented such as

Fig. 163.

Sivatherium giganteum, Falc. and Cautl. Skull with horns restored. From the Lower Pliocene, Sivalik Hills, India. $\frac{1}{12}$ nat.

Fig. 164.



Samotherium Boissieri, Forsyth Major. Skull and lower jaw. $\frac{1}{7}$ nat. A giraffe-like ruminant from the Pliocene of Samos.

Ulmus (elm), *Quercus* (Oak), and *Acer* (maple). Of the latter, many species, and even varieties, can be recognised by their

leaves and fruit, the inflorescence being sometimes admirably preserved.

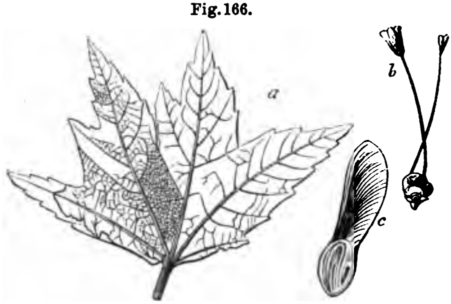
With the forms of *Acer* (Maple) leaves of the *Platanus* (Plane) very similar to the *Platanus occidentalis*, L., of the North

Fig. 165.

Acer trilobatum, Ad. Brong., normal form. Heer, Flora Tert. Helv., Pl. 114, fig. 2. Size ½ diam.

(Part only of the long stalk of the original fossil specimen is here given.)
Upper Miocene, Oeningen; also found in the Oligocene of Switzerland.

Fig. 166.



Acer trilobatum, Ad. Brong.

a. Abnormal variety of leaf. Heer, Pl. 110, fig. 16.
b. Flower and bracts, normal form. Heer, Pl. 111, fig. 21.
c. Half a seed vessel. Heer, Pl. 111, fig. 5.

American continent, have also been found at Oeningen. With the characteristic temperate forms of vegetation there also occur at Oeningen and many other places, where a Newer-Tertiary flora occurs, forms that resemble plants now characteristic of

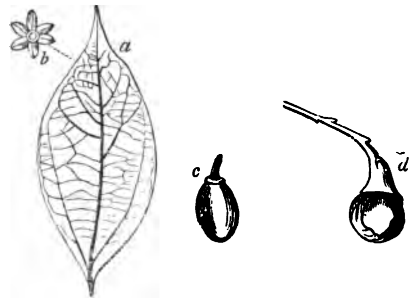
more tropical climates, such as *Cinnamomum*, *Oreodaphne*, and *Liquidambar*.

Monocotyledonous plants, like *Smilax*, are also represented in the Newer-Tertiary floras with some leaves and fruits which

Fig. 167.

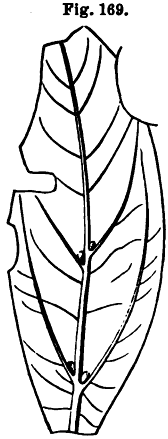
Platanus aceroides, Göpp.
Heer, Pl. 88, figs. 5–8.
Size ⅔ nat. Upper Miocene, Oeningen.
a. Leaf.
b. The core of a bundle of pericarps.
c. Single fruit or pericarp, nat. size.

Fig. 168.



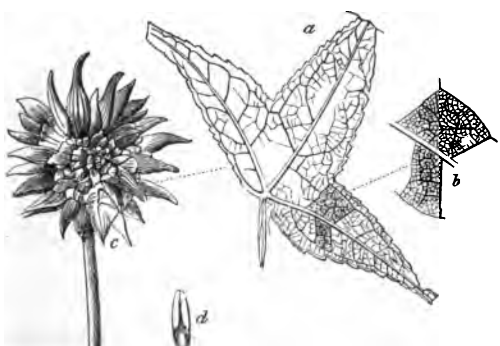
Cinnamomum polmyorphum, Ad. Brong. Upper and Lower Miocene.
a. Leaf. *b.* Flower, nat. size. Heer, Pl. 93, fig. 28. *c.* Ripe fruit of *Cinnamomum polymorphum*, from Oeningen. Heer, Pl. 94, fig. 14. *d.* Fruit of recent *Cinnamomum Camphora* of Japan. Heer Pl. 152, fig. 18.

Fig. 169.



Oreodaphne Heerii, Gaud.
Leaf, half nat. size.

Fig. 170.



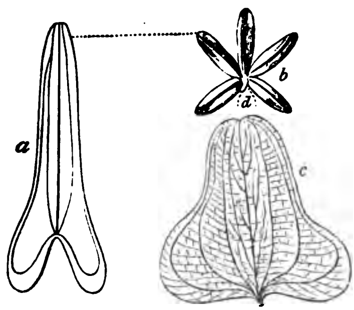
Liquidambar europæum, var. *trilobatum*, A. Brong.; sometimes 4-lobed and more commonly 5-lobed.
a. Leaf, half nat. size. *c.* Fruit, nat. size.
b. Part of same, nat. size. *d.* Seed, do., Oeningen.

have been referred by botanists to the Proteaceæ, an order now confined to Australia and South Africa. Conifers, like *Sequoia*,

Taxodium, and *Glyptostrobus* (fig. 174), also occur in considerable numbers with Ferns and still more lowly plants.

In some finely divided sediments, like those of Oeningen, not only do we find leaves exhibiting their characteristic venation and sometimes with the fruits and even the flowers of the plant attached to them, as shown in the preceding figures, but insects, retaining all their peculiar markings, and even their colours, are

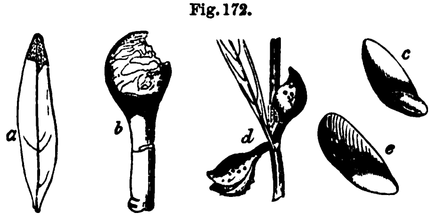
Fig. 171.



Smilax sagittifera. Heer, Pl. 30, fig. 7. Size, ½ diameter.

a. Leaf. *b.* Flower magnified, one of the six petals wanting at *d.* Upper Miocene, Oeningen. *c. Smilax obtusifolia.* Heer, Pl. 30, fig. 9, nat. size. Upper Miocene, Oeningen.

Fig. 172.



Fruit of the supposed fossil and recent species of Hakea, a genus of Proteaceæ.
a. Leaf of fossil form. *Hakea* (?) *salicina*, Heer. Upper Miocene, Oeningen; Heer, Pl. 97, fig. 29, ½ diam. *b.* Impression of woody fruit of same, showing thick stalk, ⅔ diam. *c.* Seed of same, natural size. *d.* Fruit of living Australian species, *Hakea saligna*, R. Brown, ½ diam. *e.* Seed of same, natural size.

occasionally discovered. Fig. 173 illustrates an admirably preserved specimen of one of the Hemiptera.

British representatives of the Newer Tertiary system. It is in the counties of Norfolk, Suffolk, and Essex that we obtain our most valuable information respecting the British Pliocene strata. They have been termed 'Crag,' from a provincial word which is applied to shelly sand in that district.

Newer Pliocene.—The old land surface upon which the glacial deposits collected was necessarily worn and much

denuded, and the result has been to destroy nearly every relic of the fauna and flora of the Pre-glacial or Upper Pliocene age in England. But on the eastern coast there are some remarkable deposits which underlie glacial beds, and one in particular at Cromer may be taken as the topmost member of the great formation which accumulated late in the Pliocene period, during which a gradual diminution of mean annual temperature took place culminating in the Glacial age.

Fig. 173.

Harpactor maculipes, Heer. Upper Miocene, Oeningen.

Fig. 174.

Glyptostrobus europæus, Heer. Branch with ripe fruit. Heer, Pl. 20, fig. 1. Upper Miocene, Oeningen.

Cromer Forest-bed.—Intervening between the glacial formations of Norfolk and the subjacent chalk lies what has been called the Cromer Forest-bed, near the base of a series of freshwater, estuarine, and marine formations. This buried forest has been traced from Cromer to near Kessingland, a distance of more than forty miles, being exposed at certain seasons between high and low water-mark. It is the remains of an old land- and estuarine deposit, containing the submerged stumps of trees, which appear to stand erect with their roots in the ancient soil. Associated with the stumps, and overlying them, are lignite beds, with land and freshwater shells, of species still inhabiting England with two exceptions; and the remains of the Water-lily, the Buckbean, and other plants that now live in marshes and ponds.

Through the lignite and forest-bed are scattered cones of the Scotch and Spruce firs with the leaves of the white Water-lily, yellow Pond-lily, Buckthorn, Oak, and Hazel. The fauna is a very suggestive one, and should be compared with that of the river gravels and caves (pp. 159–162) of the Pleistocene age, and with that of the Pliocene of the Val d' Arno in Italy (p. 234). About fifty mammals, some Reptilia, Amphibia, Fish, and Birds, lived in the age of this pre-glacial deposit. The genera and species studied by

Mr. E. T. Newton, of the Geological Survey, are *Canis*, *Machairodus*, *Felis*, *Martes sylvaticus*, Nils., *Gulo luscus*, L., *Ursus spelæus*, Blumenb., *U. ferox*, Geoff., *Trichecus*, *Phoca*, *Equus caballus*, L., *E. Stenonis*, Cocchi, *Rhinoceros etruscus*, Falc., *R. megarhinus*, Christol., *Hippopotamus major*, Nesti, *Sus scrofa*, L., *Bos primigenius*, Boj., *Caprovis*, *Cervus bovides*, L., *C. capreolus*, L., *C. elaphus*, L., *C. megaceros*, Hart., and nine other species of Deer, *Antilope*, *Trogontherium*, *Castor europæus*, Ow., *Arvicola*, *Mus sylvestris*, L., *Talpa*, *Sorex*, *Myogale*, *Elephas meridionalis*, Nesti, *E. antiquus*, Falc., *Balænoptera*, *Monodon*, *Delphinus*, the common Snake and Viper, Toad, and Triton, the Pike, &c. It is doubtful if *Elephas primigenius*, Blumenb., then existed.

The forest-bed is evidently an old land surface, and whilst some geologists reduce it to a clay with rootlets in it, others insist that the stumps of trees found upon it lived and grew there. Mr. Searles Wood, jun., after a long study of the localities, believed that the forest-bed resting on the chalk near Cromer, and containing the important fauna just noticed, is of Crag age—that is to say, is anterior to any glacial phenomena of importance. He considered that the Chillesford Clay has been worn into a valley at Kessingland, and that the mammalian remains found there, associated with a clay containing rootlets, are newer than those of the Cromer forest-bed.

Mr. C. Reid, of the Geological Survey, however, considers that all the tree-stumps are drifted specimens. He states that the deposit is covered by a freshwater, and this by a marine deposit. This last contains *Leda myalis*, Couth., *Trophon antiquus*, Müll., *Nucula Cobboldiæ*, Sow. The freshwater deposit has *Unio*, *Paludina*, *Planorbis*, *Limnæa*, *Succinea*, and *Helix* as genera, and *Corbicula* (*Cyrena*) *fluminalis*, Müll., and *Paludestrina* (*Hydrobia*) *marginata*, Michaud, which no longer live in the British area.

Although the relative antiquity of the forest-bed to the overlying glacial till is clear, there is some difference of opinion as to its relation to the crag presently to be described.

Chillesford and Aldeby beds.—At Chillesford, between Woodbridge and Aldborough, in Suffolk, and at Aldeby, near Beccles, in the same county, there occur stratified deposits which are composed of sands and laminated clays, with much mica, forming horizontal beds about twenty feet thick. In the upper part of the laminated clays at Chillesford a skeleton of a whale was found associated with casts of the characteristic shells, *Nucula Cobboldiæ*, Sow., *Tellina obliqua*, Sow., *Astarte borealis*, Chem. sp., and *Cyprina islandica*, L. sp. The same shells occur in a perfect state in the lower part of the formation. *Natica helicoides*, Johnst. (fig. 158, p. 176), is an example of a species formerly known only as fossil, but which has now been found living in our seas.

There are at Aldeby 70 species of mollusca, comprising the Chillesford species and some others. Of these about nine-tenths are recent. They are in a perfect state, and clearly indicate a cold climate, as two-thirds of them are now met with in Arctic regions. As a rule, the Lamellibranchiate molluscs have both valves united, and many of them, such as *Mya arenaria*, L., stand with the siphonal end upwards, as when in a living state. *Tellina balthica*, L., before mentioned (fig. 124, p. 149) as so characteristic of the glacial beds, in-

cluding the drift of Bridlington, has not yet been found in deposits of Chillesford and Aldeby age, whether at Sudbourn, Easton Bavent, Horstead, Coltishall, Burgh, or where they overlie the Norwich Crag proper at Bramerton and Thorpe.

Norwich or Fluvio-marine Crag.—The Norwich Crag is chiefly seen in the neighbourhood of Norwich, and consists of beds of incoherent sand, loam, and gravel, which are exposed to view on both banks of the Yare, as at Bramerton and Thorpe. As the beds contain a mixture of marine, land, and freshwater shells, with bones of fish and mammalia, it is clear that they have been accumulated at the bottom of the sea near the mouth of a river. The beds form patches rarely exceeding twenty feet in thickness, resting on chalk. At their junction with the chalk there invariably intervenes a bed called the 'Stone-bed,' composed of unrolled chalk flints, commonly of large size, mingled with the remains of a land fauna, comprising *Mastodon arvernensis*, Croiz. et Job., *Elephas meridionalis*, Nesti, *Elephas antiquus*, Falc., *Hippopotamus major*, Nesti, *Rhinoceros leptorhinus*, Cuv., *Trogontherium Cuvieri*, Fisch., and extinct species of Deer and Horse. Remains of the recent species of Otter and Beaver are found. The Mastodon, which is a species characteristic of the Pliocene strata of Italy and France, is the most abundant fossil, and one not found in the Cromer forest-bed just mentioned. When these flints, probably long exposed in the atmosphere, were submerged, they became covered with Barnacles, and the surface of the chalk was perforated by the *Pholas crispata*, L., each fossil shell still remaining at the bottom of its cylindrical cavity, now filled up with loose sand from the incumbent crag. This species of *Pholas* still exists, and drills the rocks between high and low water-mark on the British coast. The name of 'Fluvio-marine' has often been given to this formation, as no less than twenty species of land and freshwater shells have been found in it. They are all of species which still exist; at least only one univalve, a *Paludina*, has any claim to be regarded as extinct.

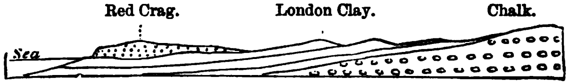
Of the marine shells, 111 in number, about 17 per cent. are extinct, according to the latest estimate given by Mr. Searles Wood in his Supplement to the Crag Mollusca; but this percentage must be regarded only as provisional. Some of the Arctic shells, which form so large a proportion in the Chillesford and Aldeby beds, are more rare in the Norwich Crag, though many northern species—such as *Rhynchonella psittacea*, Jer., *Scalaria grœnlandica*, Chemn., *Astarte borealis*, Chemn., *Panopæa norvegica*, Sow., and others—still occur. The *Nucula Cobboldiæ*, Sow., and *Tellina obliqua*, Sow., are frequent in these beds, as are also *Littorina littorea*, L., *Cardium edule*, L., and *Turritella communis*, Risso, of our seas, proving the littoral origin of the beds.

Red Crag.—Among the English Pliocene beds the next in antiquity is the Red Crag, which often rests immediately on the London clay, as in the county of Essex, illustrated in the diagram on the next page. In Suffolk it rarely exceeds twenty feet in thickness, and sometimes overlies another Pliocene deposit called the Coralline Crag. It has yielded—exclusive of 87 species regarded by Mr. Wood as derivative—248 species of mollusca, of which 92 per cent. are still living. Thus, apart from its order of superposition, its greater antiquity as a whole than the Norwich, and its still greater

antiquity than the glacial beds already described, is proved by the increased difference of its fauna from that of our seas. It may also be observed that in most of the deposits of this Red Crag, the northern forms of the Norwich Crag, and of such glacial formations as Bridlington, are less numerous, while those having a more southern aspect begin to make their appearance. Both the quartzose sand, of which it chiefly consists, and the included shells, are most commonly distinguished by a deep ferruginous or ochreous colour, whence its name. Many of the shells are littoral species. They are often rolled, sometimes comminuted, and the beds have the appearance of having been shifting sandbanks, like those now forming on the Doggerbank, in the sea, sixty miles east of the coast of Northumberland. False-bedding, the result of currents, is frequently observable, the planes of the strata being sometimes directed towards one point of the compass, sometimes to the opposite, in beds immediately superposed.

It has long been suspected that the different patches of Red Crag are not all of the same age, although their chronological relation cannot always be decided by superposition. Separate masses are characterised by shells specifically distinct or greatly varying in relative abundance, in a manner implying that the deposits containing them were separated by intervals of time. At Butley, Tunstall, Sudbourn, and in the Red Crag at Chillesford, the mollusca appear to assume their most modern aspect and indicate a colder climate than when the earliest deposits of the same period were formed. At Butley is found *Nucula Cobboldiæ*, Sow., so common in the Norwich and certain glacial beds, but unknown in the older parts

Fig. 175.



of the Red Crag. On the other hand, at Walton-on-the-Naze, in Essex, we seem to have an exhibition of the oldest phase of the Red Crag; in which the percentage of extinct forms is almost as great as in the Coralline Crag, and where *Purpura tetragona*, Sow. sp. (fig. 148, p. 173), is very abundant. The Walton Crag also indicates a warmer climate, both by the absence of many characteristic Arctic shells that are common in newer portions of the Red Crag, and by a greater proportion of Mediterranean species. *Voluta Lamberti*, Sow., an extinct species, which seems to have flourished chiefly in the antecedent Coralline Crag period, is still represented here by individuals of every age (see figs. 151, 152, p. 174).

The reversed Whelk (fig. 147, p. 173) is common at Walton, where the dextral form of that shell is unknown. Here also specimens of lamellibranchiate molluscs are sometimes found with both the valves united, showing that they belonged to this sea of the Upper Crag, and were not washed in from an older bed, such as the Coralline Crag; had such been the case, the ligament would not have held together the valves, in strata so often showing signs of the boisterous action of the waves. Such specimens of united valves are, however, rare. Mr. Searles Wood, after a most assiduous search, only detected thirteen species in this perfect condition, and among these *Mactra*

ovalis, Sow., alone is common. The true corals found in the Red Crag indicate a sea with a temperature higher than that of the present German Ocean.

At and near the base of the Red Crag is a loose bed of brown nodules, first noticed by Professor Henslow as containing a large percentage of earthy phosphates. This bed of coprolites (as it is called, because they were originally supposed to be the fæces of animals) does not always occur at one level, but is generally in largest quantity at the junction of the Crag and the underlying formation. In thickness it usually varies from six to eighteen inches, and in some rare cases amounts to many feet. It has been much used in agriculture for manure, as not only the nodules, but many of the separate bones associated with them, are largely impregnated with calcium phosphate, of which there is sometimes as much as 60 per cent. They are not unfrequently covered with barnacles, showing that they were not formed as concretions in the stratum where they now lie buried, but had been previously consolidated. Amongst the remains are those of *Mastodon arvernensis*, Croiz. et Job., *Mastodon tapiroides*, Cuv., *Elephas meridionalis*, Nesti, *Rhinoceros Schleiermacheri*, Kaup, *Tapirus priscus*, Kaup, *Hipparion* (a quadruped of the horse family), the antlers of a stag, *Cervus anoceros*, Kaup, *Hyæna antiqua*, Lank., *Felis pardoides*, Ow., and a large portion of the skull of a marine animal of the genus *Halitherium* (Dugong), which was recognised by Sir W. Flower in the collection of the Rev. H. Canham, of Waldringfield, and named by him *H. Canhami*, Flow. The tusks of a species of Walrus are also met with, together with the teeth of gigantic Sharks and the ear-bones and other portions of several species of Whales, Dolphins, and other Cetaceans.

The phosphatic nodules often include fossil Crustacea and fishes from the Eocene London Clay. Organic remains also of the older Chalk and Lias have been found, showing how great must have been the denudation of previous formations during the Pliocene period. As the older White Crag, presently to be mentioned, contains similar phosphatic nodules near its base, those of the Red Crag may be partly derived from this and other sources, such as Miocene strata.

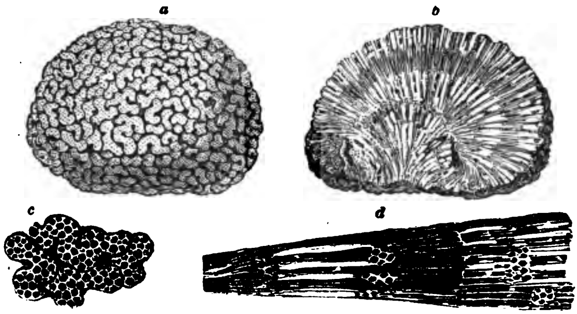
White or Coralline Crag.—The lower or Coralline Crag is of very limited extent, ranging over an area about twenty miles in length, and three or four in breadth, between the rivers Stour and Alde, in Suffolk. It is generally calcareous and marly—often a mass of comminuted shells, and the remains of Bryozoa—passing occasionally into a soft building-stone. At Sudbourn and Gedgrave, near Orford, this building-stone has been largely quarried. At some places in the neighbourhood the softer mass is divided by thin flags of hard limestone, and Bryozoa placed in the upright position in which they grew. From the abundance of these Molluscoida the lowest or White Crag obtained its popular name of 'Coralline Crag;' but true corals, or Zoantharia, are very rare in this formation.

The White Crag rarely, if ever, attains a thickness of thirty feet in any one section. Professor Prestwich, who has thrown more light than any other writer on the geology of the Crag, imagines that if the beds found at different localities were united in the probable order of their succession, they might exceed eighty feet in thickness; but since no continuous section of any such depth can be obtained, speculations as to the thickness of the whole deposit must be very

vague. A bed of phosphatic nodules, very similar to that before alluded to in the Red Crag, with remains of mammalia, has been met with at the base of the formation at Sutton.

Whenever the Red and Coralline Crag occur in the same district the Red Crag lies uppermost; and in some cases, as in the section

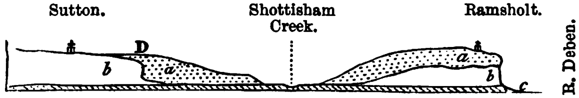
Fig. 176.



Fascicularia aurantium, Milne Edwards, ½. Family, *Tubuliporidæ*, of same author. Bryozoan of extinct genus, from the Coralline Crag, Suffolk.
a. Exterior. *b.* Vertical section of interior. *c.* Portion of exterior magnified. *d.* Portion of interior magnified, showing that it is made up of long, thin, straight tubes, united in conical bundles.

represented in fig. 177, which was well exposed to view in 1839, it is clear that the older deposit or Coralline Crag *b* had suffered denudation, before the newer formation *a* was thrown down upon it. At D there was not only seen a distant cliff, eight or ten feet high, of Coralline Crag, running in a direction NE. and SW., against which the Red Crag abuts with its horizontal layers, but this cliff occasionally overhangs. The rock composing it is drilled everywhere by *Pholades*, the holes which they perforated having been afterwards filled with sand, and covered over when the newer beds were thrown down. The older formation is shown by its fossils to have

Fig. 177.



Section near Woodbridge, in Suffolk.
a. Red Crag. *b.* Coralline Crag. *c.* London Clay.

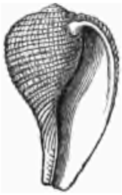
accumulated in a deeper sea, and contains very few of those littoral forms such as the Limpet (*Patella*), found in the Red Crag. So great an amount of denudation could scarcely have taken place, in such incoherent materials, without some of the fossils of the inferior beds becoming mixed up with the overlying Red Crag; hence considerable difficulty must be occasionally experienced by the palæontologist in deciding to which bed the species originally belonged.

Mr. Searles Wood estimated the total number of marine shell-bearing mollusca of the Coralline Crag at 316, of which 84 per cent. are known as living. No less than 130 species of *Bryozoa* have been found in the Coralline Crag, some belonging to genera believed to be now extinct, and of a very peculiar structure; as, for example, that represented in fig. 176, which is one of several species having a

Fig. 178.

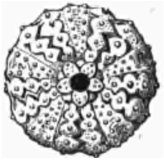
Lingula Dumortieri, Nyst, nat. size. Suffolk and Antwerp Crag.

Fig 179.



Pyrula reticulata, Lam. Coralline Crag, Ramsholt, ½.

Fig. 180.



Temnechinus excavatus, Forbes; *Temnopleurus excavatus*, Wood; nat. size. Cor. Crag, Ramsholt.

globular form. Among the Mollusca the genus *Astarte* (see fig. 149, p. 174) is largely represented, no less than fourteen species being known, and many of them being rich in individuals. There is an absence of genera peculiar to hot climates, such as *Conus*, *Oliva*, *Fasciolaria*, *Crassatella*, and others. The absence also of large cowries (*Cypræa*) is remarkable, those found belonging exclusively to the section *Trivia*. The large Volute, called *Voluta Lamberti*, Sow. (see fig. 151, p. 174), may seem an exception; but it differs in form from the Volutes of the torrid zone, and its nearest living ally, *Voluta Junonia*, Chemn., has been dredged up in the Gulf Stream in extra-tropical latitudes.

The occurrence of a species of *Lingula* at Sutton (see fig. 178) is worthy of remark, as this genus of *Brachiopoda* is now confined to more equatorial latitudes; and the same may be said still more decidedly of a species of *Pyrula*, supposed by Mr. Wood to be identical with *P. reticulata*, Lam. (fig. 179), now living in the Indian Ocean. A genus also of echinoderms, called by Professor Forbes *Temnechinus* (fig. 180), is represented in the Red and Coralline Crag of Suffolk. Its nearest analogue is in the warm eastern seas of Burma and of the Western Pacific Islands.

Older Pliocene Deposits of the South of England.—The coprolitic beds at the base of the red and white crags not unfrequently contain waterworn fragments of sandstone, which sometimes include casts of shells. These sandstone-fragments are known as 'box-stones,' and are the only relics in this country of an older Pliocene formation found in Belgium and known as the 'Diestien' or 'black crag.'

At Paddlesworth and a number of other localities along the North Downs there are sandpipes in the chalk, into which portions of the Pliocene strata which once covered the Cretaceous beds have been let down and preserved. They have yielded to Professor Prestwich, and subsequently to the officers of the Geological Survey, a number of casts of shells, which has put their Pliocene age beyond

question. They probably belong to the oldest Pliocene—the Diestien of Antwerp.

Lastly, at St. Erth's in Cornwall, there is a small patch of marine clay which has yielded a great number of marine shells and foraminifera. These also belong to species characteristic of the oldest Pliocene.

Climate of the Crag Deposits.—One of the most interesting conclusions deduced from a careful comparison of the shells of the British Pliocene strata and the fauna of our present seas was pointed out by Professor E. Forbes. It appears that during the Glacial period, an epoch intermediate, as we have seen, between that of the Crag and our own time, many shells, previously established in the temperate zone, retreated southwards to avoid an uncongenial climate, and they have been found fossil in the Newer Pliocene strata of Sicily, Southern Italy, and the Grecian Archipelago, where they may have experienced, during the era of floating icebergs, a climate resembling that now prevailing in higher European latitudes. Forbes gave a list of fifty shells which inhabited the British seas while the Coralline- and Red-Crag were forming, and which, though now living in our seas, were wanting, as far as was then known, in the glacial deposits. Some few of these species have subsequently been found in the glacial drift, but the general conclusion of Forbes remains unshaken. This view was ably supported by Mr. Searles Wood in the concluding remarks of his Supplement to the Crag Mollusca, where he pointed out how the geographical changes produced by that sinking down of land which accompanied the Glacial period may have altered the coast line, shutting out a former connection with the Mediterranean and opening for a time a new one with the Scandinavian seas.

The transport of blocks by ice, when the Red Crag was being deposited, appears to be evident from the huge size of some irregular, quite unrounded chalk flints, retaining their white coating, and 2 feet long by 18 inches broad, in beds worked for phosphatic nodules at Foxhall, four miles south-east of Ipswich. These must have been tranquilly drifted to the spot by floating ice. Mr. Prestwich also mentions the occurrence of a large block of porphyry at the base of the Coralline Crag at Sutton, which would imply that the ice-action had begun in our seas even in this older period. The mean annual temperature gradually diminished from the time of the Coralline to that of the Norwich Crag, and the climate became more and more severe, not perhaps without some oscillations of temperature, until it reached its maximum in the Glacial period.

Relation of the Fauna of the Crag to that of the recent Seas.—By far the greater number of the marine species occurring in the several Crag formations are still inhabitants of the British seas; but even these differ considerably in their relative abundance, some of the commonest of the Crag shells being now extremely scarce—as, for example, *Buccinum Dalei*, Sow.—while others, rarely met with in a fossil state, are now very common, as *Murex erinaceus*, L., and *Cardium echinatum*, L. Some of the species also, the identity of which with living forms would not be disputed by any conchologist, are nevertheless distinguishable as varieties, whether by slight deviations in form or a difference in average dimensions. Since Mr. Searles Wood first described the marine mollusca of the Crags,

the additions made to that fossil fauna have been considerable, but those made in the same period to our knowledge of the living mollusca of the British and Arctic seas and of the Mediterranean have been much greater. By this means the naturalist has been enabled to identify with existing species many forms previously supposed to be extinct. The recent careful deep-sea dredgings of the 'Challenger' and other expeditions have led to the discovery of some few Mediterranean species of shells as still living in the abysmal depths of the ocean, which were formerly regarded as extinct members of the Coralline-Crag fauna. But in spite of this resuscitation, as it might be called, of a few fossil forms, geologists find that they scarcely produce any appreciable difference in the percentage before arrived at of forms unknown as living. Such generalisations must, however, always depend on the limits assigned by different naturalists to the terms 'species' and 'variety.'

Of the strata of Miocene age, the next older division of the Tertiaries, we have no representatives whatever in this country. Between the period of the deposition of the Eocene and that of the Pliocene great movements of the land and extensive denudation must have taken place, for the small patches of Pliocene in all cases lie unconformably upon the Eocene and older rocks, while the so-called 'coprolite-beds' and 'stone-beds' at their base contain many waterworn fragments, evidently derived from the Eocene and older strata.

A full discussion of the questions connected with the age and relationships of the various Pliocene deposits in this country will be found in Prestwich's Memoirs on 'The Structure of the Crag-beds of Suffolk and Norfolk,' 'Quart. Journ. Geol. Soc.,' vol. xxvii. (1871), pp. 115, 325, 453; in Searles Wood's 'Supplement to the Monograph of Crag Mollusca,' Palæontological Society; and in the following Memoirs of the Geological Survey. 'The Geology of Norwich,' by H. B. Woodward, 'The Geology of Ipswich,' &c., by W. Whitaker, and 'The Pliocene Deposits of Britain,' by C. Reid.

CHAPTER XIV

THE OLDER TERTIARY (EOGENE OR EOCENE)

Geographical Distribution of the Older-Tertiary Strata—The London and Hampshire basins—Foraminifera, corals, echinodermata, and crustaceans of the Older Tertiaries—The Older-Tertiary Mollusca—The fish, reptiles, birds, and mammals of the period—The Older-Tertiary flora. The British Older-Tertiary Strata. Hempstead Beds—The Bembridge Series—The Headon Series—The Brockenhurst Marine Group—The Barton Sands and Clay—The Bracklesham Series—The Bournemouth Beds—The Plant-beds of Bovey Tracey and Mull—The London Clay—The Oldhaven beds and Woolwich and Reading Series—The Thanet Sands.

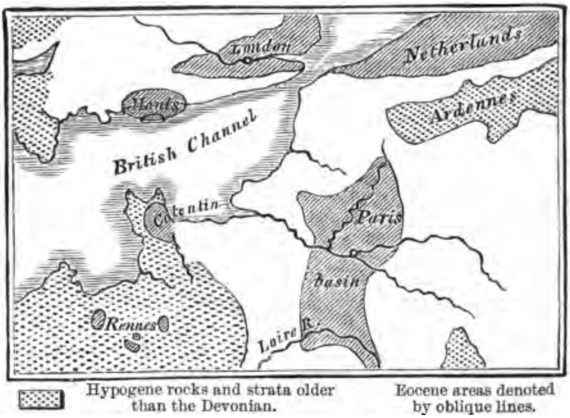
Nomenclature and Classification of the Older-Tertiary strata.—Under the name of Older Tertiaries we include not only the Eocene proper of English, French, and German authors, but the strata above them, called by Beyrich Oligocene

(and in part included by Lyell in his Lower Miocene), and those which lie beneath the Eocene as originally defined, which are sometimes called Paleocene. The distribution of these strata in England and the adjoining parts of the continent of Europe is illustrated in the accompanying sketch-map.

From this sketch-map it will be seen that the British Lower Tertiaries, with the exception of several small and outlying patches to be hereafter more particularly described, are confined to the south-east of England, where they occupy two areas known as the London and Hampshire basins respectively. Other similar areas of Older-Tertiary strata occur in Belgium and Northern France (the Paris basin), with some small scattered

Fig. 181.

Map of the principal Eocene areas of North-Western Europe.



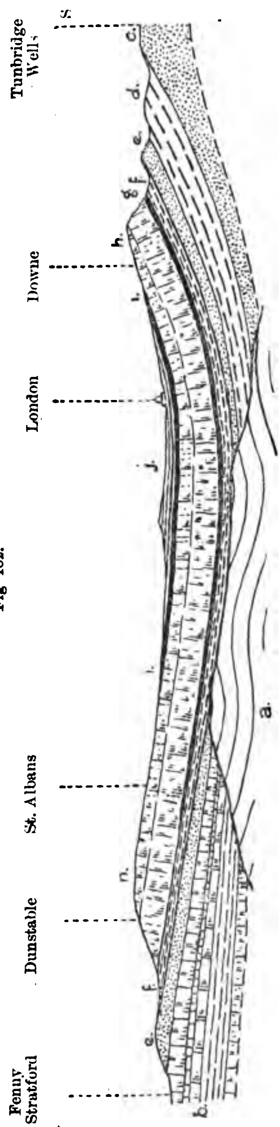
N.B. The space left blank is occupied by fossiliferous formations from the Devonian to the chalk inclusive.

outlying patches in Brittany. The correlation of the English Lower Tertiaries with those of Belgium and France is often a matter of great doubt and difficulty, notwithstanding their geographical proximity. This arises from one or other of the following circumstances:—the former prevalence of marine conditions in one basin simultaneously with fluviatile or lacustrine in the other, or the existence of land in one area causing a break or absence of all records during a period when deposits may have been in progress in the other basin. As bearing on this subject, it may be stated that we have unquestionable evidence of oscillations of level which are shown by the superposition of salt or brackish-water strata on fluviatile beds; and

those of deep-sea origin on strata formed in shallow water. Even if the upward and downward movements were uniform in amount and direction, which is very improbable, their effect in producing the conversion of sea into land, or land into sea, would be different according to the previous shape and varying elevation of the land and bottom of the sea. Lastly, denudation, marine and subaërial, has frequently caused the absence of deposits in one basin, of corresponding age to those in the other; and this destructive agency has been more than ordinarily effective on account of the loose and unconsolidated nature of the sands and clays.

Even in the case of the London and Hampshire basins (which were once united and are now separated by an anticlinal fold of the cretaceous rocks along which denudation of the tertiaries has taken place), it is often difficult to determine the exact equivalent of the strata in the two areas. The series is much more complete in the Hampshire basin than it is in the London basin, and the general order of succession in both areas is shown in the following table:—

Fig 182.



Section through the London Basin from N. to S.

a. Palæozoic rocks (Silurian, Devonian, and Carboniferous). *b.* Oolites. *c.* Hastings sands. *d.* Weald Clay. *e.* Lower Greensand. *f.* Gault. *g.* Lower Chalk with Upper Greensand at its base. *h.* Upper Chalk. *i.* Lower London Tertiaries. *j.* London Clay (outlines of Bagshot sand occur on the London Clay at Hampstead and other points).

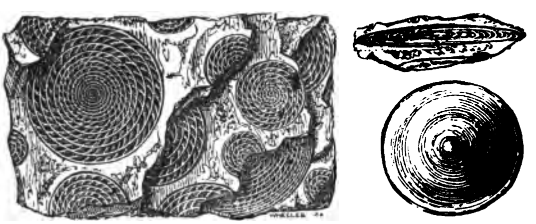
	Hampshire Basin	London Basin
MIDDLE OLIGOCENE	Hempstead Series (marine)	
LOWER OLIGOCENE	Bembridge Series (estuarine) Brockenhurst Series (marine) Headon Series (estuarine)	
UPPER EOCENE	Barton Sands (marine) Barton clay (marine) Bracklesham Series (marine)	
LOWER EOCENE	Bournemouth Beds (estuarine) Bognor Beds (marine) Plastic clay (estuarine)	Bagshot Beds (estuarine) London clay (marine) Woolwich and Reading Beds (estuarine) Thanet sands (marine)

The Lower London Tertiaries include the Woolwich and Reading beds (fluvio-marine), the pebble beds (Oldhaven series), into which they locally pass upwards, and the Thanet sands (marine), which underlie them in parts of Kent and Surrey.

The general relations of the Older Tertiaries to the underlying rocks is shown in the accompanying section (fig. 182, p. 193). There is a great unconformity between the Tertiary and the Secondary Strata, and another between the Mesozoic and the Palæozoic.

Characteristics of the Older-Tertiary fauna and flora.—Corals occur in considerable numbers in the Brockenhurst beds

Fig. 183.



Nummulites Puschi, D'Archiac, $\frac{2}{3}$. Peyrehorade, Pyrenees.

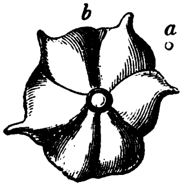
a. External surface of one of the nummulites, of which longitudinal sections are seen in the limestone. *b.* Transverse section of same.

of Hampshire (fig. 187), and reef-building forms abound in the Alpine Eocene strata. Among the Echinodermata the great prevalence of bilaterally symmetrical types (Irregulares), which had already become common in the Cretaceous rocks, is very noteworthy.

While the great majority of the species of mollusca in the Older-Tertiary strata are extinct, they nearly all belong to genera which still live in the existing seas. As a general rule, however, the genera represented in the Older Tertiaries of this country and

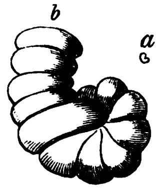
of Western Europe are such as are now found most abundantly in subtropical or even tropical seas. We are well acquainted not only with the marine form of life of the period but also with the brackish-water and freshwater types, and even with the numerous terrestrial mollusca, the shells of which are found enclosed for the most part in beds of tufaceous limestone, like those of Bembridge and Headon, in the Isle of Wight. The

Fig. 184.



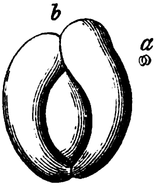
Rotalia armata, D'Orb. sp.

Fig. 185.



Peneroplis cylindraceus, Lam. sp.

Fig. 186.



Miliolina seminulum L. sp.

a. Natural size. *b*. Magnified.

general characteristics of the Oligocene and Eocene Mollusca will be understood from the figures given to illustrate the characteristic fossils of the several divisions of the strata.

The foraminifera of the Older Tertiaries are remarkable for the great development of nummulites, which were often of large size, and occurred in such prodigious numbers that many beds of limestone are almost made up of them. In Britain and Western Europe nummulites occur in comparatively small numbers, but in the Alpine regions, and in Asia and North Africa, the rocks of this age are so crowded with them that the Eocene of these regions is often spoken of as the 'Nummulitic Formation.' Other beds of limestone, of Older Tertiary age, are found to be made up of *Orbitoides* or *Miliolina* (fig. 186), and many forms of *Rotalia* (fig. 184), *Alveolina*, *Calcarina*, *Peneroplis* (fig. 185), and other genera also occur.

Fig. 187.

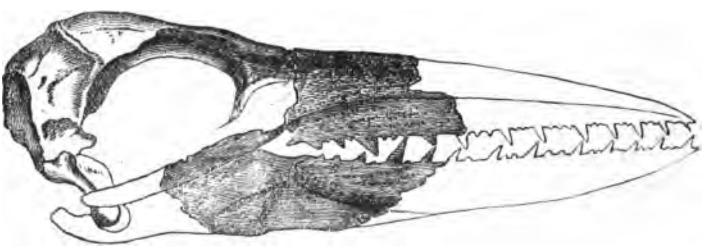
Solenastræa cellulosa, Dunc., nat. size. Brockenhurst.

Among the Crustaceans of the period, the predominance of short-tailed or Crab-like forms (Brachyura) of the Decapods over the long-tailed or Lobster-like types (Macroura) becomes very marked.

The fish are represented by great numbers of sharks, of which the teeth, often of considerable size, are the only relics which remain (see p. 211). The ordinary bony fish (Teleostei), which appeared in considerable numbers in the Cretaceous, become much more numerous in the Older Tertiaries, while the Ganoids have almost wholly disappeared.

Of the inhabitants of the land, during the Older-Tertiary period, we have numerous and interesting remains. Among reptiles we find lizards, tortoises and turtles, and crocodiles, all represented in the Older Tertiaries of the British Islands; and the serpents (Ophidia) now make their first appearance (see p. 209). The few birds found do not offer very noteworthy points of distinction from living forms; they do not belong to the remarkable synthetic types found in the Mesozoic rocks. One form, *Odontopteryx* (fig. 188), found in the London clay,

Fig. 188.



Odontopteryx toliapicus, Owen. Skull and beak restored. The mandibles are serrated, but there are no teeth in sockets as in the birds of the Cretaceous and Jurassic rocks. From the London Clay, I. of Sheppey.

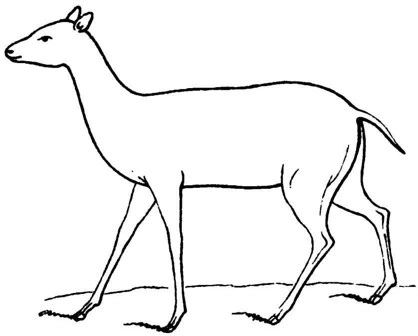
has tooth-like serrations on both jaws, like some Chelonians, but these are very different from the distinct teeth implanted in sockets found, as we shall hereafter see, in the birds of the Cretaceous and Jurassic periods.

It is in the mammalian fauna of the Older Tertiaries that we meet with the most remarkable assemblage of extinct forms. Unlike the mollusca and other lower groups of animals, the mammals of the period exhibit the widest divergence from existing types. It is generally supposed that all the Mesozoic mammals were Aplacental (Monotremes and Marsupials), and these Aplacental forms, now confined to the Australian and American continents, certainly existed in Europe during the Older-Tertiary period. But with these Aplacental mammals we have in the Older-Tertiary strata great numbers of the higher or Placental mammals, nearly all of which were remarkable *synthetic* types—that is, they combine many peculiarities which are now

found only in distinct groups. Among the Perissodactyla or Ungulates with an odd number of toes we find the tapir-like forms known as *Palæotherium* and *Lophiodon.* The Artiodactyla or Ungulates with an even number of toes are represented by many forms, such as *Xiphodon* (see fig. 189), *Anoplotherium, Anthracotherium, Hyopotamus,* &c.

In the Older Tertiaries of the Western Territories of North America a remarkable assemblage of mammals has been made known to us by the labours of Leidy, Marsh, and Cope. These seem to unite many of the characters of the Ungulates and the Proboscidians. They are all remarkable for the small size of their brain-cavities, and some of them bore several pairs of horns. Among these remarkable forms may be mentioned *Phenacodus, Dinoceras, Coryphodon, Brontotherium, Uintatherium,* &c. Some of them attained to an enormous size. A restoration of one of these remarkable gigantic mammals is shown on the following page (fig. 190).

Fig. 189.



Xiphodon gracilis, Cuvier. Restored outline.

The Carnivora of the Older Tertiaries were as different from those of the present day as were the Ungulates. Synthetic types resembling in some respects the hyænas and foxes have been referred to the genera *Hyænodon* and *Protoviverra*; while bear-like forms have been called *Amphicyon, Cynodon,* &c. With these are other forms which osteologists find a difficulty in referring to any of the orders of living mammalia, so remarkably do we find united in their structures characters now confined to distinct groups of animals. The names given to many of these animals are intended to indicate their curiously blended characters.

Lemurs are known in the Older Tertiaries, but true monkeys do not make their appearance till the succeeding period.

A number of forms of Cetacea are found in the Eocene, some corresponding in the main features of their structure with the whales of the present day, but with these we find the

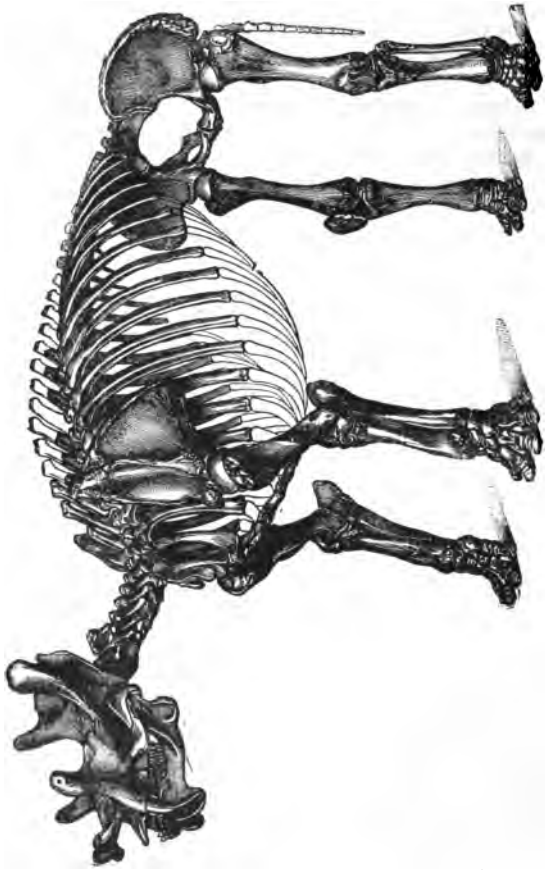


Fig. 190.

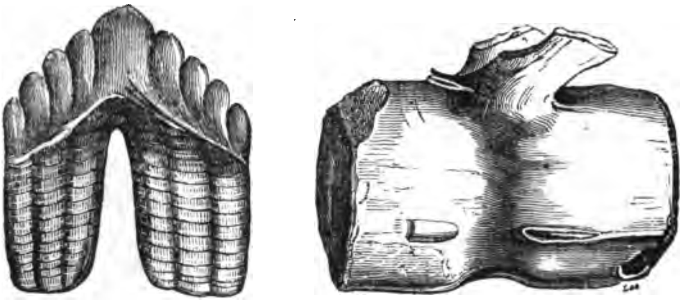
Tinoceras (*Uintatherium*) *ingens*, Marsh. $\frac{1}{30}$ nat. size. Skeleton restored by Prof. O. C. Marsh, by whom this woodcut has been supplied. From the Eocene of Wyoming, N. America.

remarkable toothed forms known as Zeuglodonts (fig. 191). The Zeuglodonts are much more abundant in North America than in Europe.

The Older-Tertiary flora shows an even closer agreement in its general characters with that of the present day than does

the flora of the Cretaceous rocks. There are many subtropical and tropical forms of ferns like *Lastræa* (fig. 192), and Conifers,

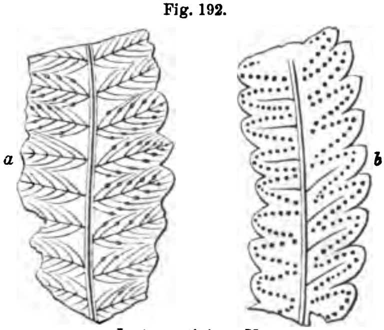
Fig. 191.



Zeuglodon cetoides, Ow.
Basilosaurus, Harlan.
Molar tooth, natural size. Vertebra, reduced.

among the latter of which we may mention the Sequoias, now confined to the Rocky Mountains, but in Tertiary times very widely distributed from the Arctic to the Equatorial zones. Palms like *Sabal* (fig. 193), *Chamærops*, *Phœnix*, and *Flabellaria* abounded in Northern Europe, and even extended into the Arctic regions. The fruits of a palm closely resembling the Indian *Nipa* (*Nipadites*) abound in our London Clay. Among the Conifers, the Sequoias, which became so abundant in Newer Tertiary times, and now appear to be on the point of extinction, are represented by the widely distributed *Sequoia Langsdorfii*, Ad. Brong. (fig. 194). Proteaceæ, now found chiefly in Australia and South Africa, are thought by many botanists to be represented among the leaves and fruits found in Older-Tertiary deposits of Europe (see fig. 195), but the correctness of these

Fig. 192.



Lastræa stiriaca, Ung.
Natural size. Oligocene and Miocene, Switzerland.
a. Specimen from Monod, showing the position of the sori on the middle of the tertiary nerves.
b. More common appearance, where the sori remain and the nerves are obliterated.

identifications has been doubted by other authorities. The chief distinction between the European Older-Tertiary flora and that of the present day is found in the prevalence of apetalous plants

Fig. 193.

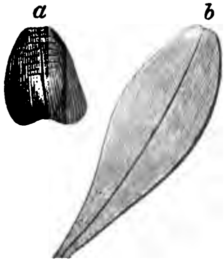
Sabal major, Unger sp. Vevay, Oligocene. (Heer, Pl. 41.)

Fig. 194.

Sequoia Langsdorfii, Ad. Brong., ½ natural size. Rivaz, near Lausanne. Oligocene, Miocene, and Lower Pliocene, Val d'Arno.

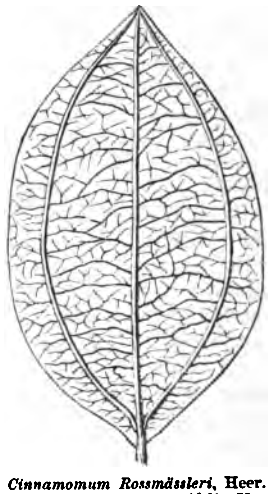
a. Branch with leaves. *b*. Young cone.

Fig. 195.



a. Fruit of a fossil Banksia.
b. Leaf of *Banksia (?) Deickeana*, Hr. Miocene of Switzerland.

Fig. 196.

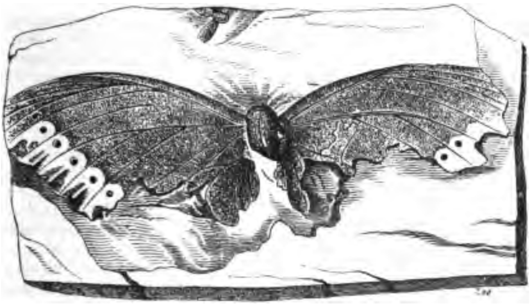


Cinnamomum Rossmässleri, Heer. *Daphnogene cinnamomifolia*, Unger. Oligocene and Miocene, Switzerland and Germany.

and the remarkable admixture of tropical forms like *Cinnamomum* (fig. 196), *Aralia*, *Ficus*, *Laurus*, *Magnolia*, &c., with the plants still living in Northern Europe, like *Acer*, *Platanus*, *Quercus*, *Ulmus*, *Carpinus*, *Populus*, *Salix*, &c.

The remains of insects are sometimes found in association with those of plants in the Older Tertiaries, as we have seen to be the case in the Newer Tertiaries. The Brown Coal of Radaboj in Croatia has been shown by Unger to contain more than two hundred species of plants, with a very rich insect fauna, including no less than ten species of *Termites* or White Ants, some of gigantic size, large dragon-flies with speckled wings, and also grasshoppers of considerable size. Even the

Fig. 197.



Mylothrites (*Vanessa*) *Pluto*, Heer, nat. size. Oligocene, Radaboj, Croatia.

Lepidoptera (butterflies and moths) are not unrepresented, and in one instance a butterfly has been found in which the pattern on the wing has escaped obliteration, and has been faithfully transmitted to us.

Arctic Eocene Flora.—A rich terrestrial flora flourished in the Arctic regions in the Older-Tertiary period, many species of which are common to strata of the same age in North-West Europe. Professor Heer has examined the various collections of fossil plants that have been obtained in N. Greenland (lat. 70°), Iceland, Spitzbergen, and other parts of the Arctic regions, and has determined that they indicate a temperate climate. Including the collections brought from Greenland later by Mr. Whymper, this Arctic flora now comprises 353 species, and that of Greenland 169 species, of which 69, or nearly two-fifths, were supposed to be identical with plants found in the Lower-Tertiary beds of Central Europe. Considerably more than half the number are trees, which is the more remarkable since at the present day trees do not exist in any part of Greenland even 10° farther south.

More than 50 species of Coniferæ have been found, including several Sequoias (allied to the gigantic Wellingtonia of California), with species of *Thujopsis* and *Salisburia* (*Gingko*), genera now found in Japan. There are also beeches, oaks, planes, poplars, maples, walnuts, limes, and even a *Magnolia*, two fruits of which have recently been obtained, proving that this splendid tree not only lived but ripened its fruit within the Arctic circle. Many of the limes, planes, and oaks were large-leaved species, and both flowers and fruit, besides immense quantities of leaves, are in many cases preserved. Among the shrubs were many ever-

greens, as *Andromeda*, and two extinct genera, *Daphnogene* and *M'Clintockia*, with fine leathery leaves, together with hazel, blackthorn, holly, logwood, and hawthorn. *Potamogeton*, *Sparganium*, and *Menyanthes* grew in the swamps, while ivy and vines twined around the forest trees, and broad-leaved ferns grew beneath their shade. Even in Spitzbergen, as far north as lat. 78° 56′, no less than 179 species of fossil plants have been obtained, including *Taxodium* of two species, hazel, poplar, alder, beech, plane-tree, and lime. Such a vigorous growth of trees within 12° of the Pole, where now a dwarf willow and a few herbaceous plants form the only vegetation, and where the ground is covered with almost perpetual snow and ice, is truly remarkable.

Professor Heer believes that the temperature of North Greenland must have been at least 30° higher than at present, while an addition of 10° to the mean temperature of Central Europe would probably be as much as was required. The chief locality where this wonderful flora is preserved is at Atanekerdluk in North Greenland (lat. 70°), on a hill at an elevation of about 1,200 feet above the sea. There is here a considerable succession of sedimentary strata pierced by volcanic rocks. Fossil plants occur in all the beds; and the erect trunks as thick as a man's body, which are sometimes found, together with the abundance of specimens of flowers and fruit in good preservation, sufficiently prove that the plants grew where they are now found. At Disco Island and other localities on the same part of the coast, good tertiary coal is abundant, interstratified with beds of sandstone, in some of which fossil plants have also been found, similar to those at Atanekerdluk.

A rather different flora was found under glacial marine drift, 1,000 feet above the present sea-level of Robeson Channel, N. lat. 81° 45′, long. W. 64° 45′. Twenty-six species were noticed, and eighteen had been found in the Older Tertiary deposits of Spitzbergen and Greenland. The Coniferæ, with *Taxodium distichum*, Rich., are abundant, this last being found in a state of bloom. *Pinus abies*, Heer, occurred, whose extreme limit is now N. lat. 69° 30′, but it spreads over 25 degrees of latitude. It was only Arctic in the Older-Tertiary times. Large reeds, poplar, birch, hazel, elm, and water-lily occurred; but the large-leaved plants like *Magnolia* were not discovered.

The similarity of these Tertiary Arctic floras to those of the Eocene of North America and of Bournemouth, Mull, and Antrim, has led to their being placed in the Older Tertiary series rather than in the Miocene as was done by Heer.

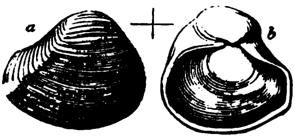
British representatives of the Older-Tertiary strata.—We have already stated that Miocene sedimentary formations do not exist in the British Islands; but lower strata, now recognised as the equivalents of the Oligocene series of the Continent, are known in Hampshire and in the Isle of Wight. So far as is known, there is little or no unconformity between these strata and the underlying true Eocene deposits. They have been termed the Fluvio-marine Series by Forbes.

An important marine deposit, found in sinking wells, opening brickyards, and making railway-cuttings in the district of the New Forest, in Hampshire—at Brockenhurst, Roydon, Lyndhurst, and other places—has yielded a very large and interesting marine fauna, including many tropical forms of Lower-Oligocene mollusca. This has been called the Brockenhurst Series. In the Isle of Wight, however, this purely marine type is either

wholly wanting or is represented only by brackish-water beds. Some difference of opinion has arisen concerning the portion of the Isle-of-Wight estuarine series which represents the marine Brockenhurst beds of the New Forest.

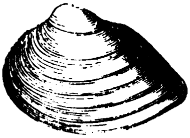
Hempstead (or **Hamstead**) **Beds.**—Of the series of strata so well exposed in the cliffs of the Isle of Wight the uppermost or Corbula-beds consist of marine sands and clays, and contain *Voluta Rathieri*, Héb., a characteristic Oligocene shell; *Corbula pisum*, Sow. (fig. 198), a species common to the Upper Eocene clay of

Fig. 198.



Corbula pisum, Sow. Hempstead Beds, Isle of Wight.

Fig 199.



Cyrena semistriata, Desh., ½ nat. Hempstead Beds.

Barton; *Cyrena semistriata*, Desh. (fig. 199), several *Cerithia*, and other shells peculiar to this series.

Next below are freshwater and estuarine marls and carbonaceous clays, in the brackish-water portion of which are found abundantly *Cerithium plicatum*, Lam. (fig. 200), *C. elegans*, Desh. (fig. 201), and *C. tricinctum*, Broc.; also *Rissoa Chastelii*, Nyst (fig. 202), a very common Klein-Spauwen shell, which occurs in each of the four subdivisions of the Hempstead series down to its base, where it passes into the Bembridge beds. In the freshwater portion

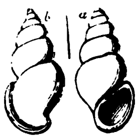
Fig. 200.

Cerithium plicatum, Lam., nat. size. Hempstead.

Fig. 201.

Cerithium elegans, Desh., nat. size. Hempstead.

Fig. 202.



Rissoa Chastelii, Nyst sp. Hempstead, Isle of Wight.

Fig. 203.

Paludina lenta, Brand, ½. Hempstead Beds.

of the same beds *Paludina lenta*, Brand. (fig. 203), occurs; a shell identified by some conchologists with a species now living, *P. unicolor*, Lam.; also several species of *Limnæa*, *Planorbis*, and *Unio*.

The next series, or middle freshwater and estuary marls, are distinguished by the presence of *Melania fasciata*, Sow., *Paludina lenta*, Brand, and clays with *Cypris*; the lowest bed contains *Cyrena semistriata*, Desh. (fig. 199), mingled with *Cerithia* and a *Panopæa*.

The lower freshwater and estuarine marls contain *Melania costata*, Sow., *Melanopsis*, &c. The bottom bed is carbonaceous, and called the 'Black band,' in which *Rissoa Chastelii*, Nyst (fig. 202),

before alluded to, is common. This bed contains a mixture of Hempstead shells with those of the underlying Bembridge series. The mammalia, among which is *Hyopotamus bovinus*, Ow., differ, so far as they are known, from those of the Bembridge beds. The *Hyopotamus* belongs to the hog tribe, or the same family as the *Anthracotherium*, of which last, seven species, varying in size from the hippopotamus to the wild boar, have been found in Italy, and in other parts of Europe, associated with the lignites of the Oligocene period.

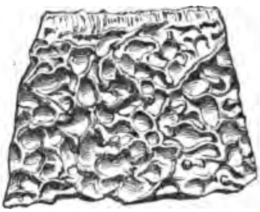
The seed-vessels of *Chara medicaginula*, Brong., and *C. helicteres*, Brong., are characteristic of the Hempstead beds generally.

Bembridge series.—These beds are about 120 feet thick, and lie immediately under the Hempstead beds near Yarmouth, in the Isle of Wight. They consist of marls, clays, and limestones of freshwater, brackish, and marine origin. Some of the most abundant shells, as *Cyrena semistriata*, Desh. var., and *Paludina lenta* (fig. 203), are common to this and to the overlying Hempstead series;

Fig. 204.

Melania turritissima, Forbes. Bembridge.

Fig. 205.



Fragment of carapace of *Trionyx*. Bembridge Beds, Isle of Wight.

but the majority of the species are distinct. The following are the subdivisions described by the late Professor Forbes:—

a. Upper marls, distinguished by the abundance of *Melania turritissima*, Forbes (fig. 204).

b. Lower marls, characterised by *Cerithium mutabile*, Lam., *Cyrena pulchra*, Sow., &c., and by the remains of *Trionyx* (see fig. 205).

c. Green marls, often abounding in a peculiar species of oyster, and accompanied by *Cerithium*, *Mytilus*, *Arca*, *Nucula*, &c.

d. Bembridge limestones, compact cream-coloured tufaceous limestones alternating with shales and marls, in all of which land-shells are common, especially at Sconce, near Yarmouth, as described by Mr. F. Edwards. The *Bulimus ellipticus*, Sow. (fig. 206), and *Helix occlusa*, F. Edw. (fig. 207), are among its best-known land-shells. *Paludina orbicularis*, F. Edw. (fig. 208), is also of frequent occurrence. One of the bands is filled with a little globular *Paludina*. Among the freshwater pulmonifera, *Limnæa fusiformis*, Sow. (fig. 210), and *Planorbis discus*, F. Edw. (fig. 209), are the most generally distributed: the latter represents or takes the place of the *Planorbis euomphalus*, Sow. (see fig. 213), of the more ancient Headon series. *Chara tuberculata*, Lyell (fig. 211), is the characteristic Bembridge 'gyrogonite' or seed-vessel.

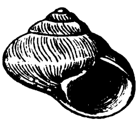
From this formation on the shores of Whitecliff Bay, Dr-

Mantell obtained a fine specimen of a fan palm, *Flabellaria Lamanonis*, Brong., a plant first obtained from beds of corresponding age in the suburbs of Paris. The well-known building-stone of Binstead, near Ryde, a limestone with numerous hollows caused by *Cyrenæ*, which have disappeared and left the moulds of their shells, belongs to this subdivision of the Bembridge

Fig. 206.

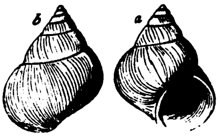
Bulimus ellipticus, Sow. Bembridge Limestone, ½ nat. size.

Fig. 207.



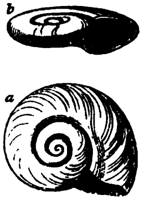
Helix occlusa, F. Edw., nat. size. Bembridge Limestone, Isle of Wight.

Fig. 208.



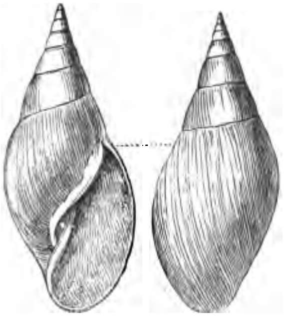
Paludina orbicularis, ½. Bembridge.

Fig. 209.



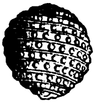
Planorbis discus, F. Edw. Bembridge, ½ diam.

Fig. 210.



Limnæa fusiformis, Sow., nat. size.

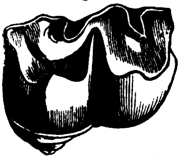
Fig. 211.



Chara tuberculata, Lyell, seed-vessel mag. Bembridge Limestone, I. of Wight.

series. In the same Binstead stone Mr. Pratt and the Rev. Darwin Fox first discovered the remains of mammalia characteristic of the gypseous series of Paris, such as *Palæotherium magnum*, Cuv., *P. medium*, Cuv., *P. minus*, Cuv., *P. curtum*, Cuv., *P. crassum*, Cuv.; also *Anoplotherium commune*, Cuv. (fig. 212), *A. secundarium*, Cuv., *Dichobune cervinum*, Ow., and *Chæropotamus Cuvieri*, Ow. The Paleothere, above alluded to, resembled the living tapir in the form of the head, and in having a short proboscis, but its molar teeth were more like those of the rhinoceros. *Palæotherium magnum*, Cuv., was of the size of a small horse, about four or five feet in height.

Fig. 212.



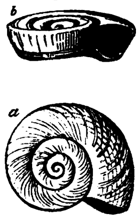
Lower molar tooth, nat. size. *Anoplotherium commune*, Cuv. Binstead, Isle of Wight.

At the base of the Bembridge series there is another group of strata of fresh- and brackish-water origin, and very variable in mineral character and thickness. Near Ryde, it

supplies a freestone much used for building, and called by Professor Forbes the Nettlestone grit. In one part ripple-marked flagstones occur, and rocks with fucoidal markings. This series of rocks was called by Professor Forbes 'the Osborne and St. Helen's series,' but its fossils do not appear to be so distinct in character from those of the Bembridge series as to necessitate a special designation for the group of beds.

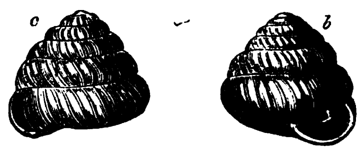
Headon series.—These beds are well seen both in Whitecliff Bay and at Headon Hill; that is, at the east and west extremities of the Isle of Wight. The upper and lower portions are freshwater, and in

Fig. 213.



Planorbis euomphalus, Sow. Headon Hill, $\frac{1}{2}$ diam.

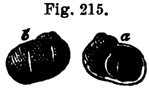
Fig. 214.



Helix labyrinthica, Say. Headon Hill, Isle of Wight; and Hordwell Cliff, Hants—also recent.

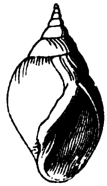
the middle a few brackish-water beds occur. Everywhere *Planorbis euomphalus*, Sow. (fig. 213), characterises the freshwater deposits, just as the allied form, *P. discus*, F. Edw. (fig. 209), does the Bembridge limestone. The brackish-water beds contain *Potamomya plana*, Sow. sp., *Cerithium mutabile*, Lam., and *Potamides cinctus*, Sow., and *Venus* (or *Cytherea*) *incrassata*, Desh., a species common to the

Fig. 215.



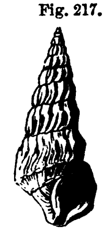
Neritina concava, Sow., nat. size. Headon series.

Fig. 216.



Limnæa caudata, Edw., $\frac{1}{2}$. Headon series.

Fig. 217.



Cerithium concavum, Sow., $\frac{2}{3}$. Headon series.

Limbourg beds and the Grès de Fontainebleau, of the Oligocene series.

Among the shells which are widely distributed through the Headon series are *Neritina concava*, Sow. (fig. 215), *Limnæa caudata*, F. Edw. (fig. 216), and *Cerithium concavum*, Sow. (fig. 217). *Helix labyrinthica*, Say. (fig. 214), a land-shell now inhabiting the United States, was discovered in this series by Mr. Searles Wood in Hordwell Cliff. It is also met with in Headon Hill, in the same beds. At Sconce, in the Isle of Wight, it occurs in the Bembridge series. The lower and middle portion of the Headon series is also met with in Hordwell

Cliff (or Hordle, as it is often spelt), near Lymington, Hants. The chief shells which abound in this cliff are *Paludina lenta*, Brand., and various species of *Limnæa*, *Planorbis*, *Melania*, *Cyclas*, *Unio*, *Potamomya*, *Dreissena*, &c.

Among the chelonians we find a species of *Emys*, and no less than six species of *Trionyx*; among the saurians an alligator and a crocodile; among the ophidians two species of land-snakes (*Paleryx*, Owen); and among the fish Sir P. Egerton and Mr. Wood have found the jaws, teeth, and hard shining scales of the genus *Lepidosteus*, or Bony Pike of the American rivers. The same genus of freshwater ganoids has also been met with in the Hempstead beds in the Isle of Wight. The bones of several birds have been obtained from Hordwell, and the remains of quadrupeds of the genera *Palæotherium* (*P. minus*, Cuv.), *Anoplotherium*, *Dichodon*, *Dichobune*, *Hyracotherium*, *Microchærus*, *Lophiodon*, *Hyopotamus*, and *Hyænodon*. From another point of view, however, this fauna deserves notice. Its geological position is considerably lower than that of the Bembridge or Montmartre beds, from which it differs almost as much in species as it does from the still more ancient fauna of the Eocene beds. It therefore teaches us what a grand succession of distinct assemblages of mammalia flourished on the earth during the Tertiary period.

Many of the marine shells of the brackish-water beds of the above series, both in the Isle of Wight and Hordwell Cliff, are common to the underlying Barton Clay; and, on the other hand, there are some freshwater shells, such as *Cyrena obovata*, Sow., which are common to the Bembridge beds.

The Brockenhurst Marine Group.—In the New Forest, at about the same horizon as the Headon and Bembridge of the Isle of Wight, we find a series of sands and clays, often crowded with marine shells, belonging to forms found only in tropical seas, with many corals. The beds are concealed by gravels, and can only be studied in artificial openings, such as brickyards and railway cuttings. The rich fauna of this important marine formation was studied by the late Mr. F. E. Edwards, and the valuable collection of shells made from it is now in the British Museum. There is still some difference of opinion among geologists as to the exact correlation of these marine strata of the New Forest with the Fluvio-marine beds of the Isle of Wight. Baron von Koenen has pointed out that no less than 46 out of the 59 Brockenhurst shells, or a proportion of 78 per cent., agree with species occurring in the Tongrian formation in Belgium.

Fig. 218.

Chama squamosa Eichw., ½. Barton.

Barton Clay.—The top of the Eocene series is formed in the Isle of Wight and Hampshire by a series of sands, which in the latter locality contain an admixture of Oligocene and Eocene forms; and this is underlaid by the celebrated Barton Clay. The latter formation consists of grey, greenish, and brown clays, with bands of sand. It is seen vertical in Alum Bay, Isle of Wight, and nearly horizontal in the cliffs of the mainland near Lymington. The thickness is 300 feet at Barton Cliff, where it is rich in marine fossils.

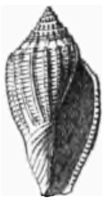
Usually, the fossils are beautifully preserved, and *Chama squamosa*, Eichw. (fig. 218), is very characteristic.

The foraminifera called Nummulites begin, when we study the Tertiary formations in a descending order, to make their appearance in great numbers in these beds. *Nummulites elegans*, Sow., and a small species called *Nummulites variolarius*, Lam. (fig. 227), are found both on the Hampshire coast and in beds of the same age in Whitecliff Bay, in the Isle of Wight. Several marine shells, among which is *Corbula pisum*, Sow. (fig. 198, p. 203), are common to the Barton

Fig. 219.

Mitra scabra, Sow., nat. size.

Fig. 220.



Voluta ambigua, Sol., ½.

Fig. 221.

Typhis pungens, Brand., nat. size.

Fig. 222.

Voluta athleta, Sol., ½. Barton and Bracklesham.

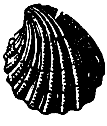
Fig. 223.

Terebellum fusiforme, Lam., nat. size. Barton and Bracklesham.

Fig. 224.

Terebellum sopita, Brand. Nat. size.

Fig. 225.



Cardita sulcata, Brand., ⅔. Barton.

Fig. 226.

Crassatella sulcata, Sow., ½. Bracklesham and Barton.

Fig. 227.

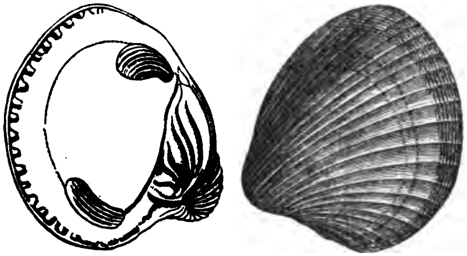
Nummulites variolarius, Lam. Middle Eocene Bracklesham Bay. *a*. Nat. size. *b*. Magnified.

beds and the higher Hempstead series, and a still greater number are common to the Headon series.

Bracklesham Beds.—Beneath the Barton Clay we find in the north of the Isle of Wight, both in Alum and Whitecliff Bays, a great series of various-coloured sands and clays for the most part unfossiliferous, and probably of estuarine origin. As some of these beds contain *Cardita planicosta*, Lam. (fig. 228), they have been identified

with the marine beds much richer in fossils seen in the coast section in Bracklesham Bay, near Chichester in Sussex, where the strata consist chiefly of green clayey sands with some lignite. Among the Bracklesham fossils, besides the Cardita, occurs the huge *Ceri-*

Fig. 228.



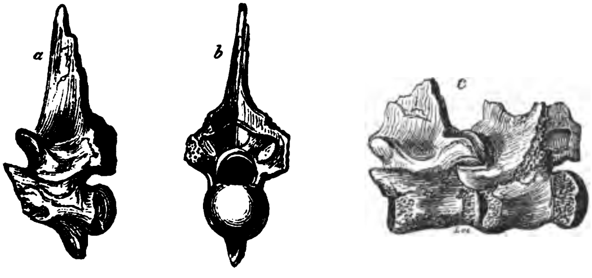
Cardita (*Venericardia*) *planicosta*, Lam., ½.

Fig. 229.

Nummulites lævigatus, Lam. Bracklesham, nat. size.

a. Section of the nummulite.
b. Group, with an individual showing the exterior of the shell.

Fig. 230.



Palæophis typhæus, Owen, ½; an Eocene sea-serpent. Bracklesham.

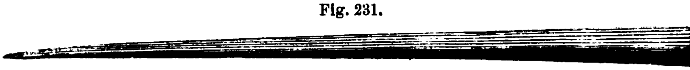
a, *b*. Vertebra, with long neural spine preserved.
c. Two vertebræ articulated together.

thium giganteum, Lam., so conspicuous in the Calcaire grossier of Paris, where it is sometimes two feet in length. *Nummulites lævigatus*, Lam. (see fig. 229), also characteristic of the lower beds of the

Calcaire grossier in France, where it sometimes forms stony layers, as near Compiègne, is very common in these English beds, together with *N. variolarius*, Lam. Out of 193 species of mollusca procured from the Bracklesham beds in England, 126 occur in the Calcaire grossier in France. It was clearly, therefore, coeval with that part of the Parisian series more nearly than with any other.

According to tables compiled from the best authorities by Mr. Etheridge, the number of mollusca now known from the Bracklesham beds in Great Britain is 393, of which no less than 240 are peculiar

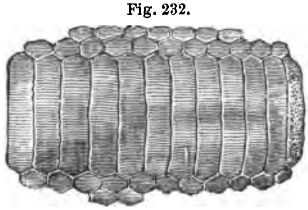
Fig. 231.



Defensive spine of *Ostracion*, ⅓. Bracklesham.

to this subdivision of the British Eocene series, while 70 are common to the older London Clay, and 140 to the newer Barton Clay. The volutes and cowries of this formation, as well as the Bryozoa and corals, favour the idea of a warm climate having prevailed, which is borne out by the discovery of the remains of a serpent, *Palæophis typhœus*, Ow. (see fig. 230), exceeding, according to Professor Owen, twenty feet in length, and allied in its osteology to the Boa, *Python*, *Coluber*, and *Hydrophis*. The compressed form and diminutive size of certain caudal vertebræ indicate so much analogy with the *Hydrophidæ* as to induce Professor Owen to pronounce this extinct ophidian to have been marine. Amongst the companions of this sea-snake of Bracklesham were an extinct crocodile (*Gavialis Dixoni*, Owen) and numerous fish, such as now frequent the seas of warm latitudes, as the *Ostracion* of the family Balistidæ, of which a dorsal spine is figured (see fig. 231), and gigantic Rays of the genus *Myliobates* (see fig. 232).

Fig. 232.



Palatal or dental plates of *Myliobates Edwardsi*, Dix., ½. Bracklesham Bay.

The teeth of sharks also, of the genera *Carcharodon*, *Otodus*, *Lamna*, *Galeocerdo*, and others, are abundant. (See figs. 233–236.)

Bournemouth Beds.—The sands and clays which intervene between the equivalents of the Bracklesham Beds and the London Clay or Lower Eocene, are well seen in the vertical beds of Alum Bay in the Isle of Wight and eastwards of Bournemouth on the south coast of Hampshire. There are some very interesting leaf-beds which underlie the marine strata of the Bracklesham clays at this locality.

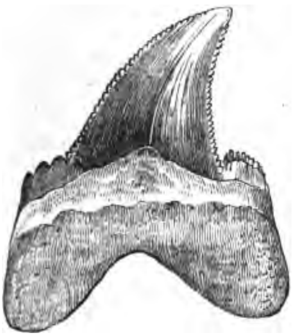
None of the beds are of great horizontal extent, and there is much cross-stratification or false bedding in the sands, with many pebble beds, and in some places black carbonaceous seams and lignite. In the midst of a leaf-bed at the base of the Bournemouth strata in Studland Bay, Dorsetshire, shells of the genus Unio attest the freshwater origin of the white clay.

No less than forty species of plants are mentioned by MM. De la

Harpe and Gaudin from this formation in Hampshire, among which plants referred to the Proteaceæ (*Dryandra*, &c.) and the fig tribe are abundant, as well as the cinnamon and several other laurineæ, with some papilionaceous plants.

It appears from the researches of Mr. Starkie Gardner that the leaves, fruits, and seeds were deposited close to where they once

Fig. 233.

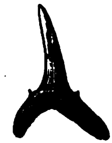


Carcharodon angustidens, Agass., nat. size.

Fig. 234.

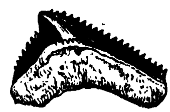
Otodus obliquus, Agass., nat. size.

Fig. 235.



Lamna elegans Agass., nat. size.

Fig. 236.



Galeocerdo latidens, Agass., nat. size.

Teeth of Sharks from Bracklesham Beds.

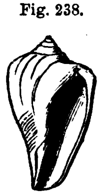
grew. The fruit *Nipadites*, closely allied to that of the existing Nipa Palm, was found with the rind and pulp more or less preserved. Tufts of leaves of *Proteaceæ*, branches of *Coniferæ*, seeds of *Hightea minima*, Bow., and *Anona* were observed. A small patch at the

Marine Shells of Bracklesham Beds

Fig. 237.

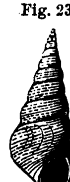
Pleurotoma attenuata, Sow., ½.

Fig. 238.



Voluta selseiensis, F. Edw., ½.

Fig. 239.



Turritella multisulcata, Lam., ½.

Fig. 240.

Lucina serrata, Sow. *a.* Magnified. *b.* Nat. size.

Fig. 241.

Conus deperditus, Brug., ⅓.

base of the cliffs was crowded with seeds of *Hightea*, *Cucummites*, and *Petrophiloides*. Pinnæ of an *Osmunda* were present. There is a fine *Irartea* palm-leaf in the British Museum from this locality.

Heer has mentioned several species which are common to this flora and that of Monte Bolca, near Verona, so celebrated for its

fossil fish, and where the strata contain nummulites and other Middle Eocene fossils. He has particularly alluded to *Aralia primigenia*, Hr. (of which genus a fruit has since been found by Mr. Mitchell at Bournemouth), *Daphnogene veronensis*, Hr., and *Ficus granadilla*, Hr., as among the species common to and characteristic of the Isle-of-Wight and Italian Eocene beds. The American types found among these Eocene plants have been noticed by the same authors.

Lignites and Clays of Bovey Tracey, Devonshire.—Surrounded by the granite and other rocks of the Dartmoor district in Devonshire, is a formation of kaolin (China-clay), sand, and lignite, long known to geologists as the Bovey-Coal formation, respecting the age of which, until late years, opinion was greatly divided. This deposit is situated at Bovey Tracey, a village distant eleven miles from Exeter in a south-west, and about as far from Torquay in a north-west, direction. The strata extend over a plain nine miles long, and they consist of the materials of decomposed and worn-down granite mixed with vegetable matter, and have evidently filled up an ancient hollow or lake-like expansion of the valleys of the Bovey and Teign.

The lignite is of bad quality for economical purposes, having a great admixture of iron pyrites, and emitting a sulphurous odour; it has, however, been successfully applied to the baking of pottery, for making which some of the fine clays are well adapted. Mr. Pengelly has confirmed Sir H. De la Beche's opinion that much of the upper portion of this old lacustrine formation has been removed by denudation.

At the surface is a dense covering of white clay and gravel with angular stones probably of the Pleistocene period, for in the clay are three species of willow and the dwarf birch *Betula nana*, L., indicating a climate colder than that of Devonshire at the present day.

Below this are Middle-Eocene strata about 300 feet in thickness, in the upper part of which are twenty-six beds of lignite, clay, and sand, and at their base a ferruginous quartzose sand, varying in thickness from two to twenty-seven feet. Below this sand are forty-five beds of alternating lignite and clay. No shells or bones of mammalia, and no insect, with the exception of one fragment of a beetle (*Bupestris*)—in a word, no organic remains, except plants—have as yet been found. These plants occur in fourteen of the beds; namely, in two of the clays, and the rest in the lignites. Amongst the species are a number of ferns—*Lastræa stiriaca*, Ung., *Pecopteris lignitum*, Heer; conifers, *Sequoia Couttsiæ*, Heer, the matted *débris* of which form a lignite bed. There are also remains belonging to the genera *Cinnamomum*, *Eucalyptus*, *Quercus*, *Salix*, *Laurus*, *Anona*, *Palmacites*, leaves of evergreen oaks, spindle trees, figs, water-lily, and the seeds of two species of vine.

The crozier-like vernation of some of the young ferns is very perfectly shown, and was at first mistaken, by collectors, for shells of the genus *Planorbis*. On the whole, the vegetation of Bovey implies the existence of a subtropical climate in Devonshire in the Middle-Eocene period.

Scotland.—Isle of Mull.—In the sea-cliffs, forming the headland of Ardtun, on the west coast of Mull, in the Hebrides, several bands of tertiary strata containing leaves of dicotyledonous plants were discovered in 1851 by the Duke of Argyll. From his description

it appears that there are three leaf-beds, varying in thickness from 1½ to 2½ feet, which are interstratified with volcanic tuff and trap, the whole mass being about 130 feet in thickness. A sheet of basalt of later age, 40 feet thick, covers the whole; and another columnar bed of the same rock, 10 feet thick, is exposed at the bottom of the cliff. One of the leaf-beds consists of a compressed mass of leaves unaccompanied by any stems, as if they had been blown into a marsh where a species of *Equisetum* grew, of which the remains are plentifully embedded in clay.

It is supposed by the Duke of Argyll that this formation was accumulated in a shallow lake or marsh in the neighbourhood of a volcano, which emitted showers of ashes and streams of lava. The materials in which the fossils are embedded may have fallen into the lake from the air as volcanic dust, or have been washed down into it as mud from the adjoining land. Even without the aid of Tertiary fossil plants, we might have decided that the deposit was newer than the chalk, for chalk flints containing cretaceous fossils were detected by the Duke in the principal mass of volcanic ashes or tuff.

The late Edward Forbes observed that some of the plants of this formation resembled those of Croatia, described by Dr. Unger; and his opinion has been confirmed by Professor Heer, who found that the conifer most prevalent was the *Sequoia Langsdorfii*, A. Brong. (fig. 194, p. 200), also *Corylus grossedentata*, Heer, an Oligocene species of Switzerland and of Menat in Auvergne. There is likewise a plane tree, the leaves of which seem to agree with those of *Platanus aceroides*, Göpp. (fig. 167, p. 181), and a fern, *Filicites hebridica*, Forbes (which is as yet peculiar as a European fossil to Mull, but which is considered by Dr. Newberry to be identical with a living American species, *Onoclea sensibilis*, L.), and a species of *Gingko*. It is thought probable that these beds may belong to a somewhat similar horizon to that of Bovey Tracey and Bournemouth, and, according to Mr. Starkie Gardner, they may be of Eocene age.

Ireland.—These interesting discoveries in Mull have led to the suspicion that the basalt of Antrim and of the Giant's Causeway, in Ireland, may be of the same Eocene age. It must be remembered, however, that the evidence of fossil plants must be accepted with considerable caution; not only is the determination of leaves by their forms and venation open to great question, in the opinion of many eminent botanists, but certain forms like *Acer*, *Sequoia*, *Gingko*, &c., had certainly a very wide range in time as well as in space. The volcanic rocks that overlie the chalk, and some of the strata associated with, and interstratified between masses of basalt, contain leaves of dicotyledonous plants, somewhat imperfect, but resembling the beech, oak, and plane, and also some coniferæ of the genera *Pinus* and *Sequoia*. These old land surfaces are exceedingly interesting.

Bagshot Beds.—In the London basin the highest strata known are the sands of Bagshot, which contain bands of pipeclay and layers of flint pebbles, but only very rarely yield traces of fossils. These strata not improbably represent the Bournemouth beds of the Hampshire basin. In the upper and middle Bagshots a few casts of marine fossils have been found in green glauconitic sandy clays, but no fossils are known from the lower Bagshots. The Bagshot beds are seen on

the top of Hampstead Hill, and cover extensive tracts in the south-east of the London basin, where they form wide, sandy heaths.

London Clay.—This formation sometimes attains a thickness of 500 feet, and consists of tenacious brown and bluish-grey clay, with layers of concretions called septaria, and is found in the London basin.

In the Hampshire basin the more sandy Bognor beds are of the same age, and, like the London clay, they are essentially marine.

The London clay was probably deposited on a sea-floor close to the entry of a large estuary and river, and the strata were formed at different depths, and some in shallow water. Several zones of fossils have been discovered by Professor Prestwich; the deepest and most marine being to the east, and the uppermost containing a terrestrial vegetation, mammalian, fish, and reptilian remains. The following genera of plants have been noticed by Bowerbank, Ettingshausen, and Gardner: *Pinus*, *Collitris*, *Salisburia*, *Musa*, *Sabal*, *Nipadites*, *Livistonia*, *Quercus*, *Liquidambar*, *Nysa*, *Magnolia*, *Juglans*, *Eucalyptus*, *Amygdalus*, and *Banksia* (?).

Fig. 242.

Nipadites ellipticus, Bow., ½.
Fossil fruit of palm, from Sheppey.

Mr. Bowerbank, in a valuable publication on these fossil fruits and seeds, has described fruits of palms of the recent type *Nipa*, now only found in the Molucca and Philippine Islands, and in Bengal. (See fig. 242.) In the delta of the Ganges, Sir J. Hooker observed the large nuts of *Nipa fruticans*, Thunb., floating in such numbers in the various arms of that great river as to obstruct the paddle-wheels of steam-boats. These plants are allied to the cocoa-nut tribe on the one side, and on the other to the *Pandanus*, or screw-pine. There are also met with three species of *Anona*, or custard apple; and cucurbitaceous fruit (of the gourd and melon family), and fruits of various species of *Acacia*.

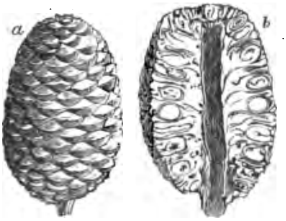
Besides fir-cones or fruit of true Coniferæ there are cones supposed to belong to the Proteaceæ; and the celebrated botanist, Robert Brown, pointed out the affinity of these to the New Holland types—*Petrophila* and *Isopogon*. Of the first there are about 50 and the second 80 described species now living in Australia.

Baron von Ettingshausen and Mr. Carruthers, having examined the original specimens now in the British Museum, state that all these cones from Sheppey (see fig. 243) may be reduced to two species, which have an undoubted affinity with the two existing Australian genera above mentioned. Other botanists, however, think that the supposed Proteaceous fruits may be referred to *Alnus* and other non-Proteaceous genera.

The contiguity of land may be inferred not only from these vegetable productions, but also from the teeth and bones of crocodiles and turtles. Of turtles there were numerous species referred to extinct genera. These are, for the most part, not equal in size to the largest living tropical turtles. A sea-snake, thirteen feet in

length, *Palæophis toliapicus*, Ow., has been described by Owen from Sheppey, and the species differs from that of Bracklesham. A crocodile, *Crocodilus toliapicus*, Cuv. et Ow., has been described by the same palæontologist, and a form nearly allied to the Gangetic Gavial also. The relics of several birds have been found belonging to the genera *Lithornis*, *Argillornis*, and *Halcyornis*. The first was a Vulturine, the second an Albatross, and the third a Kingfisher. Moreover, *Odontopteryx* (see fig. 188, p. 196) represented the birds whose bony jaw margins are produced as denticulations. The Mammalian remains are very rare; *Hyracotherium*, an odd-hoofed herbivore, and *Lophiodon* allied to the modern Tapir, have been found at the base of the formation, with a part of a jaw of a *Didelphys* (Opossum), discovered by Charlesworth, and the tooth of a Bat (*Vespertilio*). The species *Coryphodon eocænus*, Ow., most probably came from the underlying Woolwich beds. Neverthe-

Fig. 243.



Supposed Eocene Proteaceous Fruit. *Petrophiloides Richardsoni*, Bowerb. London clay. Sheppey. Natural size. *a.* Cone. *b.* Section of cone showing the position of the seeds.

Shells of the London Clay

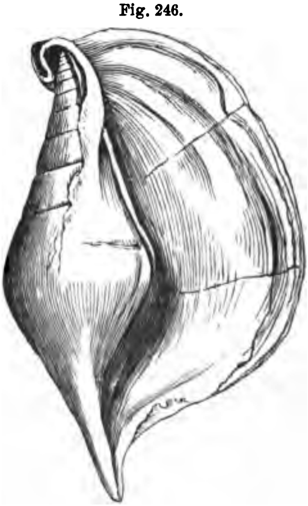
Fig. 244.

Voluta nodosa, Sow., ½. Highgate.

Fig. 245.

Phorus extensus, Sow., ½. Highgate.

Fig. 246.



Rostellaria (*Hippocrenes*) *ampla*, Brand., ⅓ of nat. size; also found in the Barton clay and Brockenhurst beds.

Fig. 247.

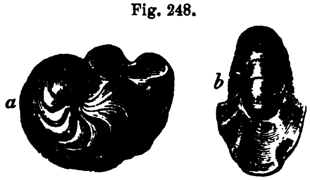
Nautilus centralis, Sow., ⅓. Highgate.

less, this scanty fauna of a Herbivore, a Marsupial and an Insectivorous Bat is not without its interest. All seem to have inhabited

the banks of the great river which floated down the Sheppey fruits. This fauna was long antecedent to the present aspect of nature in Europe and Asia, for the Alps and Himalayas were not elevated till later Oligocene times.

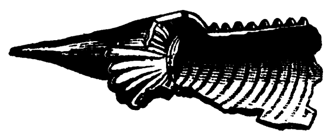
The marine shells of the London clay confirm the inference derivable from the plants and reptiles in favour of a high temperature. Thus many species of *Conus* and *Voluta* occur, a large *Cypræa*, *C. oviformis*, Sow., a very large *Rostellaria* (fig. 246), a species of *Cancellaria*,

Fig. 248.



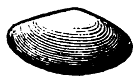
Aturia ziczac, Bronn. (syn. *Nautilus ziczac*, Sow.) London clay, Sheppey, $\frac{2}{3}$.

Fig. 249.



Belosepia sepioidea, De Blainv., nat. size. London clay. Sheppey.

Fig. 250.



Leda amygdaloides, Sow., $\frac{2}{3}$. Highgate.

Fig. 251.

Cryptodon (*Axinus*) *angulatum*, Sow., nat. size. London clay, Hornsey.

Fig. 252.

Astropecten crispatus, E. Forbes, $\frac{1}{3}$. Sheppey.

six species of *Nautilus* (figs. 247, 248), besides other Cephalopoda of extinct genera, one of the most remarkable of which is the *Belosepia* (fig. 249). Among many characteristic bivalve shells are *Leda amygdaloides*, Sow. (fig. 250), and *Cryptodon angulatum*, Sow. (fig. 251), and among the Radiata a star-fish, *Astropecten* (fig. 252).

Nearly 100 species of fish, amongst which there are a sword-fish (*Tetrapterus priscus*, Ag.), about eight feet long, and a saw-fish (*Pristis bisulcatus*, Ag.), about ten feet in length, both now foreign to the British seas.

The Crustacea were abundant, and most of them belonged to the short-tailed tribe; one species may have belonged to the true crabs. The other genera found are *Xanthopsis*, *Xantholithes*, and *Grapsus*. One of the Anomura, with a moderately long abdomen, was *Dromilites*, allied to the Sponge-crab.

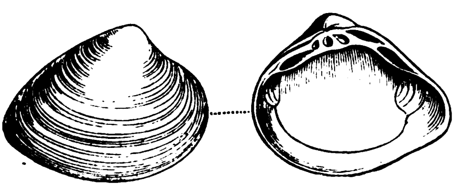
The Oldhaven Beds form the upper portion of the Woolwich and Reading series, but only occur in Kent and portions of Surrey. They consist almost entirely of rolled flint pebbles in a sandy matrix. Although only twenty to thirty feet thick, 150 species of fossils have been yielded by them, consisting of marine and estuarine shells and plant remains. The flora, so far as it goes, is interesting, and contains *Ficus*, *Cinnamomum*, and Coniferæ, and appears to be without the American and Australian types which were so dominant in later times.

Woolwich and Reading series.—This formation is apparently of the same age as the Plastic clay of the Hampshire basin, which resembles a clay used in pottery (Argile plastique) in the French series.

This formation, when studied in the basins of London, Hampshire, and Paris, presents very variable characters; but typically the beds consist, over a large area, of mottled clays and sand, with lignite, and with some strata of well-rolled flint-pebbles, derived from the chalk, varying in size, but occasionally several inches in diameter. These strata may be seen in the Isle of Wight or at Bognor, in contact with the chalk; or in the London basin, at Reading, Blackheath, and Woolwich, covering the Thanet sand. In the lowest beds banks of oysters are observed, consisting of *Ostrea bellovacina*, Lam., common also in France. In these beds at Bromley, Buckland found a large pebble to which five full-grown oysters were affixed, in such a manner as to show that they had commenced their first growth upon it, and remained attached through life.

In several places, as at Woolwich on the Thames, at Newhaven in Sussex, and elsewhere, a mixture of marine and freshwater mollusca distinguishes this member of the series. Among the latter, *Melania inquinata*, Defr. (see fig. 254), and *Cyrena cuneiformis*, Sow. (see fig.

Fig. 253.



Cyrena cuneiformis, Sow. Natural size.
Woolwich clays.

Fig. 254.

Melania (Melanatria) inquinata, Defr. $\frac{2}{3}$.
Woolwich clays.

253), are very common, as in beds of corresponding age in France. They clearly indicated points where rivers entered the Eocene sea. We usually find a mixture of brackish-water, freshwater, and marine shells, and sometimes, as at Woolwich, proofs of the river and the sea having successively prevailed on the same spot. At New Charlton, in the suburbs of Woolwich, De la Condamine discovered in 1849 a layer of sand associated with well-rounded flint pebbles, in which numerous individuals of the *Cyrena tellinella*, Fér., were seen standing endwise with both their valves united, the siphonal extremity of each shell being uppermost, as would happen if the mollusks had died in their natural position. Traced eastward towards Herne Bay, the Woolwich beds become sandy and assume a more decidedly marine character; while, in an opposite or south-western direction, the beds are more uniformly clayey, and in some places, as near Chelsea, they assume

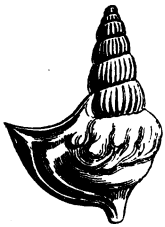
freshwater characters, and contain *Unio*, *Paludina*, and layers of lignite. Hence the land drained by the ancient river seems clearly to have been to the south-west of the present site of the metropolis. Plants of the genera *Ficus*, *Grevillea*, and *Laurus*, and leaves of the plane, poplar, and willow have been found, and the flora has affinities both with the cretaceous and the tertiary. Mr. Newton, of the Geological Survey, has described *Coryphodon*, a remarkable mammal, allied to those discovered in North America, from these beds.

Thanet sands.—The Woolwich or Plastic clay above described may often be seen in the Hampshire basin in actual contact with the chalk, constituting in such places the lowest member of the British Eocene series. But at other points another formation of marine origin, characterised by a somewhat different assemblage of organic remains, has been shown by Professor Prestwich to intervene between the chalk and the Woolwich series. The sand is micaceous,

Fig. 255.

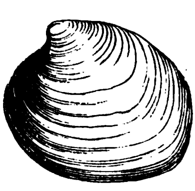
Pholadomya cuneata, Sow., $\frac{2}{3}$. Thanet sands.

Fig. 256.



Aporrhais Sowerbyi, Mant., nat. size. Thanet sands.

Fig. 257.



Cyprina Morrisii, Sow., $\frac{1}{2}$. Thanet sands.

and was derived from a granitic district. It rests on a denuded surface of the chalk, and is not found in the Hampshire basin. For these beds he has proposed the name of 'Thanet sands,' because they are well seen in the Isle of Thanet, in the northern part of Kent, and on the sea-coast between Herne Bay and the Reculvers, where they consist of sands with a few concretionary masses of sandstone, and contain, among other fossils, *Pholadomya cuneata*, Sow. (fig. 255), *Cyprina Morrisii*, Sow. (fig. 257), *Corbula longirostrum*, Desh., *Scalaria*, *Bowerbanki*, Mor., *Aporrhais Sowerbyi*, Mant. (fig. 256).

That the Eocene strata of the London and Hampshire basin are unconformable to the underlying chalk is shown by the over-lap (or 'over-step') of the Tertiary beds on the several zones of the Cretaceous. The eroded surface of the chalk with the band of green-coated flints, usually seen at the base of the Thanet Sand, is due to the action of percolating water in dissolving away the upper layers of the chalk.

Fuller details concerning the British Eocene and Oligocene strata will be found in Prof. Prestwich's various memoirs on these formations in the 'Quart. Journ. Geol. Soc.' for 1847, 1850, 1851, 1852, 1853, 1854, 1855, 1857, 1888, and the following memoirs of the Geological Survey: 'The Tertiary Fluvio-marine Formation of the Isle of Wight,' by Edward Forbes (1856); 'Geology of the Isle of Wight,' by H. W. Bristow, C. Reid, and A. Strahan (2nd ed.), 1889; the 'Geology of London' (1889), and other memoirs by W. Whitaker.

CHAPTER XV

FOREIGN DEPOSITS WHICH ARE HOMOTAXIAL WITH THE CAINOZOIC OF THE BRITISH ISLES

Tertiaries of France and Belgium—Montian—Argile plastique—Calcaire grossier—Gypsum of Montmartre—Mammals of Oligocene of Northern and Central France—Faluns of Touraine and Bordeaux—Pliocene of Northern France and Belgium—Tertiaries of Central Europe—Lower Brown Coal and Amber deposits—Mayence Basin—Pliocene of Eppelsheim—Tertiaries of Alps and Switzerland—Flysch and Nummulitic formations—Lower, Middle, and Upper Molasse—Plants and insects of Oeningen—Tertiaries of Italy—Oligocene and Miocene—Subapennine strata—Newer Pliocene of Sicily and the Val d'Arno—Tertiaries of Eastern Europe—Oligocene of Croatia—Miocene (Leithakalk and Sarmatian) of Vienna Basin—Pliocene (Congeria) strata—Tertiaries of India—Sind and Sivâlik strata—Post-pliocene deposits of Northern Europe and the Alps—Scandinavia and Russia—Central Europe—Alps and Jura—Older and Newer Palæolithic periods—Lake-dwellings—Post-pliocene of India, New Zealand, and Australia—Tertiaries of North America—Eocene and Neocene of Eastern States—Mammals and Plants of Tertiaries of the Western Territories—American Post-pliocene deposits—Glacial and Champlain periods—Tertiary Zones in Europe.

IT is a remarkable circumstance that the capitals of nearly all the great European States—London, Paris, Brussels, Rome, Vienna, Berlin, &c.—are situated on strata of Tertiary age. In most cases these great cities stand in the midst of 'basins' of Tertiary strata—that is, of isolated tracts of sediments which have been preserved by synclinal folding of the strata, preceding the denudation which has removed the Tertiary rocks from the intervening anticlinals. In this way have been formed the well-known London Basin, Paris Basin, Berlin Basin, Vienna Basin, &c. It is doubtless owing to the circumstance of their proximity to great cities with universities that the Tertiary strata and their fossils have attracted so much attention, and have had so much study devoted to them.

The Lower Eocenes of France and Belgium can be fairly well correlated with those of our own London and Hampshire basins by the assemblages of fossils contained in the several beds, though the strata themselves often differ in a very marked manner in their mineral characters from their equivalents in this country.

CAINOZOIC STRATA OF FRANCE AND BELGIUM

The general succession of the Lower Tertiary (Eocene and Oligocene) strata of France and Belgium is shown in the following table:—

	Paris Basin	Belgium and North Germany
UPPER OLIGOCENE (absent in England)	Freshwater limestone of Beauce, and millstone of Montmorency	Sternberg Beds. Sands of Cassel, Bünde, &c.
MIDDLE OLIGOCENE (Hempstead and Bembridge Beds of England)	Fontainebleau sandstone	Rupelian sands and clays. Upper Tongrian
LOWER OLIGOCENE (Brockenhurst and Headon Beds of England)	Gypsum and marls of Montmartre, with mammalian remains	Lower Tongrian and clays of Egeln
UPPER EOCENE (Barton Beds of England)	Freshwater limestones of St. Ouen, marine sand of Beauchamp	Wemmelian sands and clays
MIDDLE EOCENE (Bracklesham Beds and London clay)	Coarse marine limestone known as the 'Calcaire grossier' and sands of Cuise	Laekenian, Bruxellian, Paniselian, Ypresian
LOWER EOCENE (Woolwich and Reading Beds and Thanet Sands)	Plastic clay and lignite of Soissons, sand of Bracheux, marl of Meudon	Landenian, Heersian, Montian

The Miocene is well developed in Southern France and Switzerland; but in France and Western Europe generally, as in England, the Pliocene is only represented by thin and comparatively insignificant deposits, and it is necessary to go to Italy and the Vienna basin to find the full development of the Pliocene System.

Paleocene Beds ('Montian').—In the coarse limestone of Mons in Belgium and in the Marls of Meudon in the Paris basin we have strata which are perhaps older than any in the British Islands. The Belgian beds contain a few Cretaceous Echinodermata, and some authors have proposed to rank these oldest known Tertiary strata of Europe as a distinct group, to which they apply the name of Paleocene.

The Calcaire grossier of Mons is lower than the horizon of the Thanet Sands, and fills a depression in the chalk, being 300 feet thick. Upwards of 400 species of fossils have been obtained from it. Vast numbers of Gastropoda, Lamellibranchiata, Bryozoa, Foraminifera (*Quinqueloculina*), and calcareous Algæ are found. Some limestones, sands, and marine conglomerates at Rilly, beneath the Meudon conglomerate, are the lowest members of the French Eocene, and are older than the Thanet Sands, but slightly younger than the Calcaire de Mons at the base of the Belgian Eocene. The conglomerates rest on the chalk, and their fauna is marine and tertiary.

The Heersian of Belgium is also slightly older than the Thanet sands, and contains the flora of Gelinden. In this flora we find many species of *Dryophyllum*, a genus somewhat resembling that of the modern American Chestnut Oak. But the flora as a whole has no satisfactory alliance with the Eocene flora of America.

Sables de Bracheux.—The marine sands called the Sables de Bracheux (a place near Beauvais) were considered by M. Hébert to be older than the Lignites and Plastic clay, and to coincide in age with the Thanet Sands of England. At La Fère, in the department of Aisne, in a deposit of this age, a fossil skull has been found of a

quadruped called by Blainville *Arctocyon primævus*, Blain., and supposed by him to be related both to the Bear and to the Kinkajou (*Cercoleptes*). This creature is perhaps the oldest known tertiary mammal. The Lower Landenian of Belgium resemble and are of the same age as the Thanet Sands.

Lignites of Soissonnais and Argile plastique.—At a slightly higher horizon in the Paris basin are extensive deposits of sands, with occasional beds of clay used for pottery. Fossil oysters (*Ostrea bellovacina*, Lam.) abound in some places; and in others there is a mixture of fluviatile shells, such as *Cyrena cuneiformis*, Sow. (fig. 253, p. 217), *Melania inquinata*, Defr. (fig. 254, p. 127), and others, frequently met with in the Woolwich beds of the London basin. Layers of lignite are also intercalated.

In the year 1855, the tibia and femur of a large bird, equalling at least the ostrich in size, was found at Meudon, near Paris, at the base of the Plastic clay. This bird, to which the name of *Gastornis parisiensis*, Héb., has been assigned, appears, from the Memoirs of MM. Hébert, Lartet, and Owen, to belong to an extinct genus. Professor Owen refers it to the class of wading land birds rather than to an aquatic species.

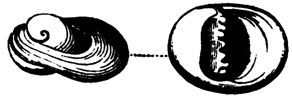
That a formation so much explored for economical purposes as the Argile plastique around Paris, and the clays and sands of corresponding age near London, should never have afforded any vestige of a feathered biped previously to the year 1855, shows what diligent search and what skill in osteological interpretation are required before the existence of birds of remote ages can be established.

The Ypresian and Paneselian of Belgium represent the English London clay.

Lower Eocene.—There is no exact equivalent of the London clay in the Paris basin, and the next strata, above the Argile plastique, are the Sables de Cuise.

Sables de Cuise.—These are of considerable thickness, especially at Cuise-Lamotte, near Compiègne, and other localities in the Soissonnais, about fifty miles N.E. of Paris, from which about 800 species of shells have been obtained, many of them common to the Calcaire grossier and the Bracklesham beds of England, and many peculiar. *Nummulites planulatus*, Lam., is very abundant, and the most characteristic shell is

Fig. 258.



Nerita conoidea, Lam.

the *Nerita conoidea*, Lam., a fossil which has a very wide geographical range; for, as M. d'Archiac remarks, it accompanies the Nummulitic formation from Europe to India, having been found in Cutch, near the mouths of the Indus, associated with *Nummulites scabra*, Lam. No less than 33 shells of this group are said to be identical with shells of the London clay proper. It is believed by Professor Prestwich that the sands of Cuise are probably newer than the London clay, and perhaps older than the Bracklesham beds of England.

The Middle Eocene is composed of the Calcaire grossier, formed of limestones, and siliceous limestones, with sandy glauconitic beds at the base, all highly fossiliferous.

Lower Calcaire grossier, or Glauconie grossière.—The lower part of the Calcaire grossier, which often contains much green earth, is characterised at Auvers, near Pontoise, to the north of Paris, and still more in the environs of Compiègne, by the abundance of nummulites, consisting chiefly of *N. lævigatus*, Brug. sp., *N. scabra*, Lam., and *N. Lamarcki*, D'Orb., which constitute a large proportion of some of the stony strata, though these same foraminifera are wanting in beds of a similar age in the immediate environs of Paris.

The upper division of this group consists in great part of beds of

compact, fragile limestone, with some intercalated green marls. The shells belong to such varied genera as *Cerithium*, *Corbula*, *Limnæa*, *Paludina*, *Cyclostoma*, &c. In the green marls the bones of reptiles and mammalia (*Palæotherium* and *Lophiodon*) have been found. The middle division, or Calcaire grossier proper, consists of a coarse limestone, often passing into sand. It contains the greater number of the fossil shells which characterise the Paris basin. No less than 400 distinct species have been procured from a single spot near Grignon, where they are embedded in a calcareous sand, chiefly formed of comminuted shells, in which, nevertheless, individuals in a perfect state of preservation, both of marine, terrestrial, and freshwater species, are mingled together. Some of the marine shells may have lived on the spot; but the shells of *Cyclostoma* and *Limnæa*, being land and freshwater forms, must have been brought thither by rivers and currents.

Nothing is more striking in this assemblage of fossil mollusca than the great proportion of species referable to the genus *Cerithium*. There occur no less than 137 species of this genus in the Paris basin, and almost all of them in the Calcaire grossier. Most of the living *Cerithia* inhabit the sea near the mouths of rivers, where the waters are brackish, so that their abundance in the marine strata now under consideration is in harmony with the hypothesis that the Paris basin formed a gulf into which several rivers flowed.

In some parts of the Calcaire grossier round Paris, certain beds occur of a stone used in building, and called by the French geologists 'Miliolite limestone.' It is almost entirely made up of millions of microscopic shells, of the size of minute grains of sand, which belong to the Foraminifera. The Bruxellian and Laekenian of Belgium represent the French Calcaire grossier.

The Middle Eocene of Belgium approximates to the English type, and the Upper or Wemmelian series is full of *Nummulites variolarius*, Lam.

Upper Eocene.—The strata of this age in the Paris basin are continuous with the lower Oligocene. They are the marine gypseous series, yellow and greenish marls, with *Cerithium tricarinatum*, Desh., and *Pholadomya ludensis*, Desh.

Beneath these are the 'Sables moyens,' with green sands, overlying the nearly freshwater limestone of St. Ouen. They rest on the Grès de Beauchamp, a marine sandstone with corals, sharks' teeth, and *Nummulites variolarius*, Lam.

Lacustrine gypseous series of Montmartre.—These strata, commencing with white marls and blue marls at the top, and having the important gypsum beds below, represent the Lower Oligocene, and are most largely developed in the central parts of the Paris basin, among other places in the hill of Montmartre, the fossils of which were first studied by Cuvier.

The gypsum, there quarried for the manufacture of plaster of Paris, occurs as a granular crystalline rock, and, together with the associated marls, contains land and fluviatile shells, and the bones and skeletons of birds and quadrupeds. Several land-plants are also met with, among which are fine specimens of *Flabellaria*. The remains also of freshwater fish, and of crocodiles and other reptiles, occur in the gypsum. The skeletons of mammalia are usually isolated, often entire, the most delicate extremities being preserved; as if the carcases, clothed with their flesh and skin, had been floated down soon after death, and while they were still swollen by the gases generated by their first decomposition. The few accompanying shells are of those light kinds which frequently float on the surface of rivers, together with wood.

In this formation the relics of about fifty species of quadrupeds, including the genera *Palæotherium*, *Anoplotherium*, and

others, have been found, all extinct, and nearly four-fifths of them belonging to the Perissodactyle or odd-toed division of the order *Ungulata*. The *Anoplotheridæ* form a family intermediate between pachyderms and ruminants, and belong to the even-toed group of Ungulates. With these Ungulata were associated a few carnivorous animals, among which were *Hyænodon* and a species allied to the dog (*Cynodictis parisiensis*, Gerv. sp.). Of the *Rodentia* was found a squirrel-like form; of the *Cheiroptera*, a bat; while the family *Didelphidæ* of the *Marsupialia*, now confined to America, are represented by a true Opossum (*Didelphys*).

Of birds, about 17 species have been discovered, five of which are still undetermined. The skeletons of some are entire, but none are referable to existing species. Crocodiles, and tortoises of the genera *Emys* and *Trionyx*, are found.

Fossil footprints.—Amongst the numerous interesting remains of this series are footprints of animals, which occur at six different levels. M. Desnoyers discovered large slabs, which are now in the Museum at Paris, where, on the upper planes of stratification, the indented footmarks were seen, while corresponding casts in relief appeared on the lower surfaces of the strata of gypsum which were immediately superimposed.

Upper Oligocene of Northern France.—The Calcaire de la Beauce constitutes a large tableland between the basins of the Loire and the Seine. It is associated with marls and other deposits, such as may have been formed in marshes and shallow lakes in the newest part of a great delta. Aquatic plants (*Chara*) left their stems and seed-vessels, which are now found embedded both in marl and flint, together with freshwater and land shells. Some of the siliceous rocks of this formation are used extensively for millstones. The flat summits or platforms of the hills round Paris, and large areas in the forests of Fontainebleau, as well as the Plateau de la Beauce, already alluded to, are chiefly composed of these freshwater strata. Next to these, in the descending order, are marine sands and sandstone, commonly called the Grès de Fontainebleau.

Next in succession, forming the Middle Oligocene, are the Sables d'Etampes with ferruginous sands at Paris, resting on marls with *Ostrea cyathula*, Lam., and *Corbula subpisum*, D'Orb. These cover the Calcaire de Brie, which overlies clay and green marl with *Cerithium plicatum*, Lam., and *Cyrena convexa*, Lam.

Oligocene of Central France.—Lacustrine strata, belonging, for the most part, to the same age as the Calcaire de la Beauce, are again met with further south, in Auvergne, Cantal, and Velay. They appear to be the monuments of ancient lakes, which, like some of those now existing in Switzerland, once occupied the depressions in a mountainous region.

The study of these regions possesses a peculiar interest, for we are presented in Auvergne with the evidence of a series of events of astonishing magnitude and grandeur, by which the original form and features of the country have been greatly changed, yet never so far obliterated but that they may still, in part at least, be restored in imagination. Great lakes have disappeared, and lofty volcanic mountains have been formed by the reiterated emission of lava, preceded and followed by showers of sand and scoriæ. Deep valleys have been subsequently furrowed out through masses of lacustrine and volcanic origin; and at a still later date, new cones have been thrown up in these valleys, new lakes have been formed by the damming up of rivers, and several assemblages of quadrupeds, birds, and plants, Eocene, Oligocene, Miocene, and Pliocene, have followed in succession. Yet the region has preserved from first to last its geographical identity; and we can still picture to our minds its external condition and physical structure,

before these wonderful vicissitudes began, or while a part only of the series of changes had been completed. There was a first period when the spacious lakes, of which we still may trace the boundaries, lay at the foot of mountains of moderate elevation, unbroken by the bold peaks and precipices of Mont Dore, and unadorned by the picturesque outline of the Puy-de-Dôme, or of the volcanic cones and craters now covering the granitic platform. During this earlier scene of repose, deltas were slowly formed; beds of marl and sand, several hundred feet thick, deposited; siliceous and calcareous rocks precipitated from the waters of mineral springs; shells and insects embedded together with the remains of the crocodile and tortoise, the eggs and bones of water-birds, and the skeletons of quadrupeds, most of them of genera and species characteristic of the period. To this tranquil condition of the surface succeeded the era of volcanic eruptions, when the lakes were drained, and when the fertility of the district was probably enhanced by the igneous matter ejected from below, and poured down upon the more sterile granite. During these eruptions, which appear to have taken place towards the close of the Miocene epoch, and which continued during the Pliocene, various assemblages of quadrupeds successively inhabited the district, amongst which are found the genera *Mastodon*, *Rhinoceros*, *Elephas*, *Tapir*, *Hippopotamus*, together with the ox, various kinds of deer, the bear, the hyæna, and many beasts of prey which ranged the forest or pastured on the plain, and were occasionally overtaken by a fall of burning cinders, or buried in flows of mud such as accompany volcanic eruptions. Lastly, these quadrupeds became extinct, and gave place in their turn to the species now existing. There are no signs, during the whole time required for this series of events, of the sea having intervened, or of any denudation which may not have been accomplished by rivers and floods accompanying repeated earthquakes.

Auvergne.—The most northern of the freshwater groups is situated in the valley plain of the Allier, which lies within the department of the Puy-de-Dôme, being the tract which went formerly by the name of the Limagne d'Auvergne. The principal divisions into which the lacustrine series may be separated are the following:—1st, Sandstone, grit, and conglomerate, including red marl and red sandstone; 2ndly, Green and white foliated marls; 3rdly, Limestone, or travertin, often oolitic in structure; 4thly, Gypseous marls. The whole rest on granite.

It seems that, when the ancient lake of the Limagne first began to be filled with sediment, no volcanic action had yet produced lava and scoriæ on any part of the surface of Auvergne. No pebbles, therefore, of lava, were transported into the lake—no fragments of volcanic rocks embedded in the conglomerate. But at a later period, when a considerable thickness of sandstone and marl had accumulated, eruptions broke out, and lava and tuff were deposited, at some spots, alternating with the lacustrine strata. It is not improbable that both cold and hot springs, holding different mineral ingredients in solution, became more numerous during the successive convulsions attending this development of volcanic agency, and thus deposits of calcium carbonate and sulphate, with silica, and other substances were produced. The subterranean movements may then have continued until they altered the relative levels of the country, and caused the waters of the lakes to be drained off, and the further accumulation of regular freshwater strata to cease.

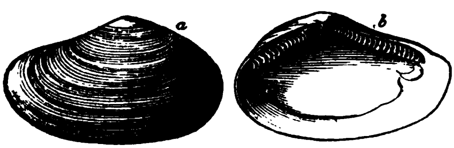
Oligocene mammalia of the Limagne.—It is scarcely possible to determine the age of the oldest part of the freshwater series of the Limagne, large masses both of the sandy and marly strata being devoid of fossils. Some of the lowest beds may be of Upper Eocene date, although, according to Pomel, only one bone of a *Palæotherium* has been discovered

in Auvergne. But in Vélay, in strata containing some species of fossil mammalia common to the Limagne, no less than four species of *Palæotherium* have been found by Aymard, and one of these is generally supposed to be identical with *Palæotherium magnum*, Cuv., an undoubted Upper Eocene fossil, of the Paris gypsum, the other three being peculiar to the Limagne.

Not a few of the other mammalia of the Limagne belong undoubtedly to genera and species elsewhere proper to the Oligocene. Thus, for example, the *Cainotherium* of Bravard, a genus not far removed from the *Anoplotherium*, is represented by several species. A small species of rodent, of the genus *Titanomys* of Meyer, is common to the Oligocene of Mayence and the Limagne d'Auvergne, and a remarkable carnivorous genus, the *Hyænodon* of Laizer, is represented by more than one species. The same genus has also been found in the marls of Hordwell Cliff, Hampshire, just below the level of the Bembridge Limestone, and therefore in a formation of about the same age as the gypsum of Paris. Several species of opossum (*Didelphys*) are met with in the same strata of the Limagne. The total number of mammalia enumerated by Pomel as appertaining to the Oligocene fauna of the Limagne and Vélay, falls little short of a hundred, and with them are associated some large crocodiles and tortoises, and some ophidians and batrachians. The birds of the Limagne and those of the Mayence basin are, according to Milne Edwards, almost identical. Among those of the Limagne are extinct species related to the duck, stork, and many of the swallow tribe; also several kinds of pheasants and species of trogon and parrot, birds which are now confined to Asia and the tropics of both hemispheres.

Oligocene of Belgium: Tongrian and Rupelian.—These strata are marine and fluvio-marine, and are well developed near Tongres, in Limbourg. The Middle Oligocene, or Rupelian, includes the Marine series of the Bolderberg and Argile de Boom (so called from the villages of Boom and Rupelmonde, south of Antwerp), which cover a fluvio-marine group with *Cerithium* and *Pectunculus* and the Argile de Henis The lower division, or Tongrian, includes the sands in the neighbourhood of Tongres, and is the continuation of the Lower Oligocene, or Egeln series of Germany, corresponding with the upper part of the Gypseous series of Montmartre, and with the Headon series of England.

Fig. 259.



Leda Deshayesiana, Duch., nat. size.

Having this base, it is not difficult to comprehend the extension of the overlying middle Oligocene. The Argile de Henis is equivalent to the green clays with *Cyrena* of the Mayence basin, with the deposits at Bembridge in the Isle of Wight, and with the upper Montmartre green marls which overlie the Gypseous series.

The deposits of Klein-Spauwen, a village to the west of Maestricht, which are above the Henis clay, are of the same age as the Grès de Fontainebleau and as our Hempstead series.

The Upper, or Marine division of the Middle Oligocene of Belgium, with the Argile de Boom and the Bolderberg sands, is the equivalent

of the Septarien-Thon of Germany and the Upper Lacustrine series of the Calcaire de la Beauce of France.

Halitherium is found in the Middle Oligocene, and the teeth of *Carcharodon*, *Myliobates*, *Lamna*, and other sharks are common to it and the Lower Oligocene, or Tongrian. Many small crustacea are found in the Middle series, and a fossil lobster (*Homarus*). The *Nautilus* (*Aturia zicsac*, Sow.) occurs in the upper deposit, and many Gastropoda are found, some being Lower and others Upper Oligocene forms. *Leda Deshayesiana*, Duch. (fig. 259), is common to the Lower and Middle series, and *Cerithium plicatum*, Lam., is found in the Middle series.

The Miocene strata of France.—Faluns of Touraine.—The strata which we meet with next in the ascending order are those which have no representatives in the British Islands, and were called by some geologists 'Middle Tertiary;' in 1833 the name of Miocene was proposed for these strata, the 'faluns' of the valley of the Loire in France being selected as a type.

The name 'faluns' is given provincially by French agriculturists to shelly sand and marl spread over the land in Touraine, just as the similar shelly deposits called Crag were formerly much used in Suffolk to fertilise the soil, before the coprolitic or phosphatic nodules came into use. Isolated masses of such faluns occur from near the mouth of the Loire, in the neighbourhood of Nantes, to as far inland as a district south of Tours. They are also found at Pontlevoy, on the Cher, about seventy miles above the junction of that river with the Loire, and thirty miles S.E. of Tours. Deposits of the same age also appear under different mineral conditions near the towns of Dinan and Rennes, in Brittany. The scattered patches of faluns are of slight thickness, rarely exceeding fifty feet; and between the district called La Sologne and the sea they repose on a great variety of older rocks; being seen to rest successively upon gneiss, clay-slate, various secondary formations (including the chalk), and lastly, upon the upper freshwater limestone of the Parisian tertiary series, which, as before mentioned, stretches continuously from the basin of the Seine to that of the Loire, and which is of Oligocene age. Fragments of this limestone are included in the 'faluns.'

At some points, as at Louans, south of Tours, the shells are stained with ferruginous matter, not unlike those of the Red Crag of Suffolk. The species are, for the most part, marine, but a few of them belong to land and fluviatile genera. Remains of terrestrial quadrupeds are here and there intermixed, belonging to the genera *Dinotherium* (fig. 161, p. 177), *Mastodon*, *Rhinoceros*, *Hippopotamus*, *Chæropotamus*, *Dichobune*, *Cervus*, and others, and these are accompanied by Cetacea of extinct species.

The molluscan fauna of the faluns indicate a moderate depth of water and a climate warmer than that of Europe at the present time. Thus it contains seven species of *Cypræa*, some larger than any existing cowry of the Mediterranean, several species of *Oliva*, *Ancillaria*, *Mitra*, *Terebra*, *Pyrula*, *Fasciolaria*, and *Conus*. The genus *Nerita*, and many others, are also represented by individuals of a type now characteristic of equatorial seas, and wholly unlike any Mediterranean forms. These proofs of a more elevated temperature seem to imply the higher antiquity of the faluns as compared with the Suffolk Crag, and are in perfect accordance with the fact of the smaller proportion of mollusca of recent species found in the faluns.

The principal grounds for referring the French faluns to the Miocene epoch is the fact that the recent species are in a decided minority as compared with the living forms; and most of the falunian shells of living species are now inhabitants of the Mediterranean, the coast of Africa, and

the Indian Ocean; in a word, these falunian shells present a less northern character, and point to the prevalence of a warmer climate. They indicate a state of things farther removed from the present condition of Central Europe in physical geography and climate, and doubtless, therefore, receding farther from our era in time.

The Miocene strata of Bordeaux and South of France.—A great extent of country between the Pyrenees and the Gironde is overspread by tertiary deposits of various ages and chiefly of Miocene date. Some of these, near Bordeaux, coincide in age with the faluns of Touraine, already mentioned, but many of the species of shells are peculiar to the south. The succession of beds in the basin of the Gironde implies several oscillations of level by which the same wide area was alternately converted into sea and land or into brackish-water lagoons, and finally into freshwater ponds and lakes.

Among the freshwater strata of this age near the base of the Pyrenees are marls, limestones, and sands, in which the eminent comparative anatomist, M. Lartet, obtained a great number of fossil mammalia common to the faluns of the Loire and the Miocene beds of Switzerland, such as *Dinotherium giganteum*, Kaup., and *Mastodon angustidens*, Cuv. More recently M. Gaudry has enumerated 16 species of vertebrata from strata of this age at Mont Léberon in Vaucluse, among which are *Machairodus cultridens*, Cuv., *Rhinoceros Schleiermacheri*, Kaup., *Dinotherium giganteum*, Kaup., and the gigantic ruminant *Helladotherium Duvernoyi*, Gaud. et Lart., rivalling the Giraffe in stature. This herbivore had a wide range over Europe and Asia, its remains having been found in Greece and India. But the most remarkable of all the remains found in the Miocene strata of the South of France were the bones of Quadrumana, or of the ape and monkey tribe, which were discovered by M. Lartet in 1837. They were referred by MM. Lartet and de Blainville to a genus closely allied to the Gibbon, to which they gave the name of *Pliopithecus*. In 1856, M. Lartet described another species of the same family of long-armed apes (*Hylobates*), which he obtained from strata of the same age at Saint-Gaudens in the Haute-Garonne. The fossil remains of this animal consisted of a portion of a lower jaw with teeth and the shaft of a humerus. It is supposed to have been a tree-climbing frugivorous ape, equalling Man in stature. As the trunks of oaks are common in the lignite beds in which it lay, it has received the generic name of *Dryopithecus*.

Pliocene of France.—There is some difficulty in distinguishing the scattered beds of this age in France from those of the Miocene; but in some instances there is unconformity between the two series. Some of the deposits of Pliocene age are marine, but the majority are of freshwater and terrestrial origin. At Dixmerie, in Brittany, there is a sandy deposit in which are fossil shells of species found in the British Crag, but mixed with a preponderance of Miocene forms. In Roussillon a marine deposit is found containing similar shells. The sands of Landes appear to be of Pliocene age. In the Cotentin there are marls with marine shells and bones of *Halitherium*. These are all deposits of the age of the Crags, but, owing to the localities being more to the south, the northern element of the molluscan fauna does not predominate in them.

The mammalian fauna of the period was part of a very important continental assemblage of animals, and whilst some of the deposits are of the age of the Forest-bed and Norwich Crag, others are older, and approach the Miocene.

At Saint-Prest, near Chartres, the characteristic Pliocene elephant (*Elephas meridionalis*, Nesti) is found, with *Rhinoceros etruscus*, Falc., and *Trogontherium*, associated with *Hippopotamus major*, Nesti.

At Montpellier a marine deposit overlies sand with a fossil monkey,

Semnopithecus monspessulanus, Gerv., *Mastodon*, *Rhinoceros megarhinus*, Christol., *Tapirus*, *Hyæna*, *Felis*, *Lutra*, *Lagomys*, *Sus*, *Cervus*, *Antilope*, and *Hyænarctos*.

In the Auvergne, numerous species of deer, a few antelopes, and *Elephas*, *Hippopotamus*, *Hyæna*, *Hipparion*, and *Machairodus* have been found.

In the valley of the Saône, deposits contain *Elephas meridionalis*, Nesti, *E. antiquus*, Falc., *Mastodon arvernensis*, Croiz. et Job., *M. Borsoni*, Hays, *Equus stenonis*, Cocchi; and in the Limagne the same Mastodons were accompanied by *Rhinoceros*, *Machairodus*, *Tapirus*, and *Antilope*.

Count Saporta has examined the flora of the Older Pliocene of Maximieux, near Lyons, and found the genera *Bambusa*, *Liquidambar*, *Liriodendron*, *Acer*, *Glyptostrobus*, *Magnolia*, *Populus*, and *Salix* There was a marked abundance of evergreens, which gives the flora a southern aspect; but with a diminishing mean temperature, the flora became transitional between that of the Miocene and the present day.

The Pliocene deposits of Belgium, as now limited by Mourlon, consist of a lower division—the Diestien, at the base of which are sands with great quantities of bones of Cetaceans with excessive elongation of the head (*Heterocetaceæ*). On the ferruginous sands of this system rest sands with *Isocordia cor*, L., covered by others with *Fusus contrarius*, Sow. (*Trophon antiquum*, Müll.). These two last groups compose the Scaldisian system, and contain a vast quantity of Cetacean remains, with those of fish and also shells.

Beneath the Diestien is the Black Crag, or Antwerp Crag, which is considered to be a passage bed between the Miocene and Pliocene formations. It is rich in Cetacean bones.

CAINOZOIC STRATA OF CENTRAL EUROPE

Oligocene of Germany.—The division of the Oligocene was first established by the study of strata in North Germany. Professor Beyrich has made known to us the existence of a long succession of marine strata in North Germany, which lead, by an almost gradual transition, from beds of Lower Oligocene age to others of the age of the Upper Miocene. Although some of the German lignites called Brown Coal belong to the upper parts of this series, others of them are referred to the Lower Miocene and many to the Lower and Middle Oligocene. Professor Beyrich confines the term 'Miocene' to those strata which agree in age with the faluns of Touraine, and he proposed the term 'Oligocene' for the older formations of the district, including some formerly classed with the Upper Eocene as well as those called Lower Miocene by earlier authors.

Oligocene beds of marine and freshwater origin occupy depressions and detached areas which present very distinct faunas and floras.

The Lower Oligocene is marine above. The marine beds of Egeln, with corals and mollusca, cover an amber-bearing glauconitic sand—the amber containing many beautifully preserved insects — and at the base of all are conglomerates and clays and pitch-coal —the Lower Brown Coal series. The flora is largely composed of Conifers, Oaks, Laurels, *Magnolia*, *Dryandroides*, *Ficus*, with *Sabal*, *Flabellaria*, and other Palms. The facies is subtropical and North American, with some Indian and Australian types.

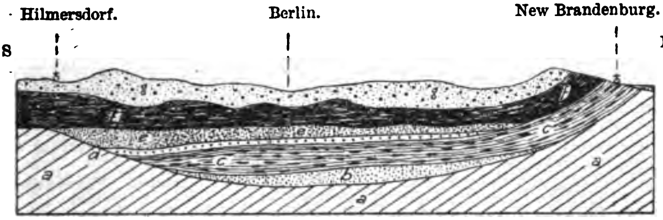
The Middle Oligocene is the Septarien-Thon, with *Leda Deshayesiana*, Duch. (see fig. 259, p. 225), and in some places plants are found forming local Brown coals. The upper deposits are Brown coals, found in the Lower Rhine district, and the flora contains the genera *Acer*, *Cinnamomum*, *Juglans*, *Nyssa*, *Pinites*, *Quercus*, having a sub-tropical American facies. Some

marine beds contain *Terebratula grandis*, Blumenb.

Mayence basin.—An elaborate description has been published by Dr. F. Sandberger of the Mayence tertiary area, which occupies a tract from five to twelve miles in breadth, extending for a great distance along the left bank of the Rhine from Mayence to the neighbourhood of Mannheim, and is also found to the east, north, and south-west of Frankfort-on-Main. the lowest is the marine sand of Weinheim.

The Miocene of the Mayence Basin.—This underlies the bone-bed of Eppelsheim, and is fluviatile, estuarine, and terrestrial in its nature. The beds contain a fauna which differs from that of Eppelsheim, none of the genera being identical; *Dinotherium*, *Palæomeryx*, *Microtherium*, *Hippotherium* occur in them. Amongst the shells are *Dreissena*, *Mytilus*,

Fig. 260.



Section through the basin of Berlin. *a.* Older Rocks. *b.* Lower Oligocene (Glauconite sands, &c.). *c.* Middle Oligocene (Septaria clay). *d.* Stettin sand. *e.* Upper Oligocene (sands). *f.* Miocene (Lignite or Brown Coal deposits). *g.* Drift. (After Berendt and Kayser.)

De Koninck, of Liège, has pointed out that the purely marine portion of the deposit contained many species of shells common to the Klein-Spauwen beds and to the clay of Rupelmonde, near Antwerp.

The deposits underlie the sandstones with leaves and the *Cerithium* limestones of the Miocene, and may be divided into three groups. The upper is a Cyrena marl with *Cyrena semistriata*, Desh., and *Cerithium plicatum*, Lam.; the middle is a clay with *Leda Deshayesiana*, Duch.; and and *Littorinella*. Among the plants are *Sabal* and *Cinnamomum*.

The Miocene rests on the Cyrena marl of Oligocene age.

German Pliocene.—At Eppelsheim, near Worms, there is a group of sands and gravel with lignite, containing mammalian remains, overlying a freshwater formation of later Miocene or Older Pliocene age. The mammalia belong to the genera *Dinotherium*, *Mastodon*, *Rhinoceros*, *Hippotherium*, *Sus*, *Felis*, and *Cervus*.

CAINOZOIC STRATA OF THE ALPINE DISTRICTS AND SWITZERLAND

Nummulitic Formation of Southern Europe, Asia, &c. In the Alps and Southern Europe generally, the Lower Eocene is represented by the sandy and argillaceous strata known as Flysch and Macigno, which contain few fossils except impressions of fucoids; while the upper part of the Eocene is developed on a grand scale, and contains beds of limestones crowded with Nummulites. To these strata the name of Nummulitic is given.

Of all the rocks of the Eocene period, no formations are of such great geographical importance as the Upper and Middle Eocene, or Nummulitic. Separate groups of strata are often characterised by distinct species of Nummulites. The nummulitic limestone of the Swiss Alps rises to more than 10,000 feet above the level of the sea, and attains here and in other mountain-chains a thickness of several thousand feet. It may be said to play a far more conspicuous part than any other Tertiary group in the solid framework of the earth's crust, whether in Europe, Asia, or North Africa. It occurs in Algeria and Morocco, and has been traced from Egypt, where it was largely quarried of old for the building of the pyramids, into Asia Minor, and across Persia by Bagdad to the mouths of the Indus. It has been observed not only in Cutch, but in the mountain-ranges which separate Sind from Persia, and which form the passes leading to Cabul; and it has been followed still farther eastward into India, as far as Eastern Bengal amongst the Himalayas, and the frontiers of China.

Dr. T. Thomson found Nummulites in Western Thibet at an elevation of no less than 16,500 feet above the level of the sea. One of the species, which occurs very abundantly on the flanks of the Pyrenees, in a compact crystalline marble, is called by M. d'Archiac *Nummulites Puschi* (fig. 183, p. 194). The same is also very common in rocks of the same age in the Carpathians.

When we have once arrived at the conviction that the Nummulitic formation occupies a middle and upper place in the Eocene series, we are struck with the comparatively modern date to which some of the greatest revolutions in the physical geography of Europe, Asia, and Northern Africa must be referred. All the mountain-chains, such as the Alps, Pyrenees, Carpathians, and Himalayas, into the composition of whose central and loftiest parts the Nummulitic strata enter bodily, could have had no such altitude till after the Middle Eocene period. During that period the sea mainly prevailed where these chains now rise, for the Nummulites were unquestionably inhabitants of salt water.

The Lower Molasse of Switzerland (Aquitanian).—In Switzerland the Nummulitic formation is covered by great deposits of Oligocene, Miocene, and Pliocene age. These strata, which are of great thickness and include deposits of marine, brackish-water, and freshwater origin, are called by the Swiss geologists Molasse.

The Miocene or Molasse Formation of Switzerland consists of the following members:—

1. The Upper Freshwater Molasse, including the Lacustrine Marls of Oeningen.

2. The Marine Molasse corresponding in age with the faluns of Touraine.

3. The Lower Freshwater Molasse.

Nearly the whole of this Lower Molasse is freshwater; yet some of the inferior beds contain a mixture of marine and fluviatile shells, the *Cerithium plicatum*, Lam., a well-known Oligocene fossil, being one of the marine species. Notwithstanding, therefore, that some of these Oligocene strata consist of old shingle beds several thousand feet in thickness, as in the Rigi near Lucerne, and in the Speer near Wesen, forming mountains 5,000 and 7,000 feet above the sea, the deposition of the whole series must have begun at or below the sea-level.

The conglomerates, as might be expected, are often very unequal in thickness in closely adjoining districts; since in a littoral formation accumulations of pebbles would swell out in certain places where rivers entered the sea, and would thin out to comparatively small dimensions where no streams, or only small ones, came down to the coast. For ages, in spite of a gradual depression of the land and adjacent sea-bottom, the rivers continued to cover the sinking area with their deltas; until finally, the subsidence being in excess, the sea of the Middle Molasse gained upon

the land, and marine beds were thrown down over the dense mass of freshwater and brackish-water deposit, called the Lower Molasse, which had previously accumulated.

Flora of the Lower Molasse.—In part of the Swiss Molasse which belongs exclusively to the Oligocene Period, the number of plants has been estimated at more than 500 species. The series may best be studied on the northern borders of the Lake of Geneva between Lausanne and Vévay. The strata there consist of alternations of conglomerate, sandstone, and finely laminated marls with fossil plants. The flora contains, according to Heer, 108 species, of which 81 pass up into the flora of Oeningen.

The proofs of a warmer climate and the excess of arborescent over herbaceous plants and of evergreen trees over deciduous species, are characters common to the whole flora, which are intensified as we descend to the inferior deposits.

Among the Coniferæ the *Sequoia* is common at Rivaz, and is one of the most universally distributed plants in the Oligocene of Switzerland.

Lastræa stiriaca, Unger, has a wide range in the Tertiary period from strata of the age of Oeningen to the lowest part of the Swiss Molasse. In some specimens, as shown in fig. 192, p. 199, the fructification is distinctly seen.

Among the laurels several species of *Cinnamomum* are very conspicuous. Besides *C. Polymorphum*, Ad. Brong., before figured (fig. 168, p. 181), another species also ranges from the Lower to the Upper Molasse of Switzerland, and is very characteristic of different deposits of Brown Coal in Germany. It has been called *Cinnamomum Rossmässleri*, Heer. (See fig. 196, p. 200.)

American character of the flora.—If we consider not merely the number of species but those plants which constitute the mass of the Oligocene vegetation, we find the European part of the fossil flora very much less prominent than in the Oeningen beds, while much more conspicuous are American forms, such as evergreen oaks, maples, poplars, planes, *Liquidambar*, *Robinia*, *Sequoia*, *Taxodium*, &c. There is also a much greater fusion of the characters now belonging to distinct botanical provinces than in the Miocene flora, and we find this fusion still more strikingly exemplified when we go back to the antecedent Eocene and Cretaceous periods.

Middle or Marine Molasse of Switzerland ('Helvetian'). Some of the beds of the marine or middle series reach a height of 2,470 feet above the sea. A large number of the shells are common to the faluns of Touraine, the Vienna basin, and other Upper Miocene localities. The terrestrial plants play a subordinate part in the fossiliferous beds, yet more than ninety of them are enumerated by Heer as belonging to this Falunian division, and of these more than half are common to the subjacent lower molasse, while a proportion of about 45 in 100 are common to the overlying Oeningen flora; 26 of the 92 species are peculiar. Remains of an ape (*Dryopithecus*) have been found in these beds.

Upper Miocene freshwater Molasse.—This formation is best seen at Oeningen, in the valley of the Rhine, between Constance and Schaffhausen, a locality celebrated for having produced in the year 1700 the supposed human skeleton called by Scheuchzer 'homo diluvii testis,' a fossil afterwards demonstrated by Cuvier to be a reptile, or aquatic salamander, of larger dimensions than even its great living representative the salamander of Japan.

The Oeningen strata consist of a series of sandstones, marls, and limestones, many of them thinly laminated, which appear to have slowly accumulated in a lake probably fed by springs holding calcium carbonate in solution.

All the fossil-bearing strata of Oeningen were evidently formed with extreme slowness. Although they are in the aggregate not more than a few yards in thickness, and have only been examined in a small

area, they give us an insight into the state of animal and vegetable life in part of the Miocene period, such as no other region in the world has elsewhere supplied. In the year 1859, Prof. Heer had already determined no less than 475 species of plants and more than 800 insects from these Oeningen beds. He supposed that a river entering a lake floated into it some of the leaves and land insects, together with the carcases of quadrupeds, among others that of a great Mastodon. Occasionally, during tempests, twigs and even boughs of trees with their leaves were torn off and carried for some distance so as to reach the lake. Springs, containing calcium carbonate, seem at some points to have supplied calcareous matter in solution, and to have thus formed a tufaceous limestone or travertine.

The Upper Miocene flora of Oeningen contains some tropical forms, like Palms, *Cinnamomum*, and Vines, with leaves and fruits of trees like *Acer*, and *Platanus*; the cones and leaves of pines such as *Glyptostrobus*; and forms referred by many botanists to the Proteaceæ.

The conclusions drawn from the insects are for the most part in perfect harmony with those derived from the plants, but they have a somewhat less tropical and less American aspect, the South European types being more numerous. On the whole, the insect fauna is richer than that now inhabiting any part of Europe. No less than 844 species were enumerated by Heer from the Oeningen beds alone, the number of specimens which he examined being 5,080. Nearly all the species belong to existing genera. Almost all the living families of Coleoptera are represented; but, as we might have anticipated from the preponderance of arborescent and ligneous plants, the wood-eating beetles play the most conspicuous part, the Buprestidæ and other long-horned beetles being particularly abundant. The patterns and some remains of the colours both of *Coleoptera* and *Hemiptera* are preserved at Oeningen (fig. 178, p. 183).

CAINOZOIC STRATA OF THE ITALIAN PENINSULA

It is in the Italian peninsula and in Sicily that we find the grandest development of the Newer-Tertiary strata.

Oligocene of Italy.—In the hills of which the Superga, near Turin, forms a part, there is a great series of Tertiary strata which pass downwards into the Oligocene. Even in the Superga itself there are some fossil plants which, according to Heer, have never been found in Switzerland so high as the marine Molasse. In several parts of the Ligurian Apennines, as at Dégo and Carcare, the Oligocene appears containing some Nummulites, and at Cadibona, north of Savona, freshwater strata of the same age occur, with beds of lignite enclosing remains of the *Anthracotherium magnum*, Cuv., and *A. minus*, Cuv., besides other mammalia enumerated by Gastaldi. In these beds a great number of the Oligocene plants of Switzerland have been discovered.

The Marine Oligocene is of great importance, containing only few Nummulites, but a most interesting reef-building coral fauna.

Miocene strata of Italy.—We are indebted to Signor Michelotti for a valuable work on the Miocene shells of Northern Italy. Those found in the hill called the Superga, near Turin, have long been known to correspond in age with the faluns of Touraine, and they contain so many species common to the Miocene strata of Bordeaux as to lead to the conclusion that there was a free communication between the northern part of the Mediterranean and the Bay of Biscay during the Miocene Period. In the adjoining hills to the Superga, these Tertiary strata pass down into the Oligocene.

Older Pliocene of Italy.—Subapennine strata. — The Apennines, as is well known, are composed chiefly of Secondary or Mesozoic rocks, forming a chain

which branches off from the Ligurian Alps and passes down the middle of the Italian peninsula. At the foot of these mountains, on the side both of the Adriatic and the Mediterranean, are found low hills occupying the space between the older chain and the sea. Their strata belong both to older and newer members of the tertiary series. The strata, for example, of the Superga, near Turin, are Miocene; those of Asti and Parma Older Pliocene, as is the blue marl of Siena; while the shells of the overlying yellow sand of the same territory approach more nearly to the recent fauna of the Mediterranean, and may be Newer Pliocene.

We have seen that most of the fossil shells of the Older Pliocene strata of Suffolk which are of recent species are identical with mollusca now living in British seas, yet some of them belong to Mediterranean species, and a few even of the genera are those of warmer climates. We might therefore expect, in studying the fossils of corresponding age in countries bordering the Mediterranean, to find some species and genera of warmer latitudes among them. Accordingly, in the marls belonging to this period at Asti, Parma, Siena, and parts of the Tuscan and Roman territories, we observe the genera *Conus*, *Cypræa*, *Strombus*, *Pyrula*, *Mitra*, *Fasciolaria*, *Sigaretus*, *Delphinula*, *Ancillaria*, *Oliva*, *Terebellum*, *Terebra*, *Perna*, *Plicatula*, and *Corbis*, some characteristic of tropical seas, others represented by species more numerous or of larger size than those now proper to the Mediterranean.

Older Pliocene flora of Italy.—The Val d'Arno blue clays, with some subordinate layers of lignite, exhibit a richer flora than the overlying Newer Pliocene beds, and one receding farther from the existing vegetation of Europe. They also comprise more species common to the antecedent Miocene period. Among the genera of flowering plants, M. Gaudin enumerates pine, oak, evergreen oak, plum, plane, alder, elm, fig, laurel, maple, walnut, birch, buckthorn, hiccory, sumach, sarsaparilla, sassafras, cinnamon, *Glyptostrobus*, *Taxodium*, *Sequoia*, *Persea*, *Oreodaphne*, *Cassia*, and some others. This assemblage of plants indicates a warm climate, but not so subtropical a one as that of the Upper Miocene period.

Newer Pliocene strata of Sicily.—At several points north of Catania, on the eastern sea-coast of Sicily—as at Aci-Castello, Trezza, and Nizzeti for example—marine strata, associated with volcanic tuffs and basaltic lavas, are seen, which belong to a period when the first igneous eruptions of Mount Etna were taking place in a shallow bay of the Mediterranean. They contain numerous fossil shells, and out of 142 species that have been collected, all but eleven are identical with species now living. Some few of these may possibly still linger in the depths of the Mediterranean.

There is probably no part of Europe where the Newer-Pliocene formations enter so largely into the structure of the earth's crust, or rise to such heights above the level of the sea, as Sicily. They cover nearly half the island, and near its centre, at Castrogiovanni, reach an elevation of 3,000 feet. Seguenza has divided the deposits into three groups, the oldest or Zanclean being composed of marls and limestones. Many tropical shells are found, and out of 504 species about 17 per cent. only are found living in the Mediterranean.

Large tropical shells and many littoral and deep-sea corals and foraminifera are found in this series. On the top of the Zanclean are blue clays followed by Ostian yellow sands. The Zanclean is Older Pliocene, and the superincumbent strata are Newer Pliocene.

South of the plain of Catania is a region in which the tertiary beds are intermixed with volcanic matter, which has been for the most part the product of submarine eruptions. It appears that, while the Newer Pliocene strata were in course of deposition at the bottom of the sea, volcanoes burst out

beneath the waters, like that of Graham Island in 1831, and these explosions recurred again and again at distant intervals of time. Volcanic ashes and sand were showered down and spread, by the waves and currents, so as to form strata of tuff, which are found intercalated between beds of limestone and clay containing marine shells, the thickness of the whole mass exceeding 2,000 feet.

No shell is more conspicuous in these Sicilian strata than the great scallop, *Pecten Jacobæus*, L., (fig. 155, p. 175), now so common in the neighbouring seas. The more we reflect on the preponderating number of this and other recent shells, the more are we surprised at the great thickness, solidity, and height above the sea of the rocky masses in which they are entombed, and the vast amount of geographical change which has taken place since their origin.

Newer Pliocene strata of the Upper Val d'Arno.—When we ascend the Arno for about 10 miles above Florence, we arrive at a deep, narrow valley, called the Upper Val d'Arno, which appears to have been a lake at a time when the valley below Florence was an arm of the sea. The horizontal lacustrine strata of this upper basin cover an area 12 miles long and 2 broad. The depression which they fill has been excavated out of Eocene and Cretaceous rocks, which form everywhere the sides of the valley and exhibit highly inclined stratification. The thickness of the more modern and unconformable beds is about 750 feet, of which the upper 200 feet consist of Newer-Pliocene strata, while the lower are Older Pliocene. The newer series are made up of sands and a conglomerate called 'sarsino.' Cocchi has found a *Macacus* in them, and a second species has been discovered by Forsyth Major, and these are amongst the last fossil Monkeys of Europe. Among the embedded fossil mammalia are *Mastodon arvernensis*, Croiz. et Job., *Elephas meridionalis*, Nesti, *Rhinoceros etruscus*, Falc., *Hippopotamus major*, Nesti, and remains of the Bear, Hyæna, and of Felidæ, nearly all of which occur in the Cromer forest bed.

In the same upper strata are found, according to Gaudin, the leaves and cones of a *Glyptostrobus* closely allied to one now inhabiting the north of China and Japan. This conifer had a wide range in time, having been traced back to the Oligocene strata of Switzerland and being common at Oeningen in the Upper Miocene.

CAINOZOIC STRATA OF EASTERN EUROPE

In Eastern Europe and the Vienna basin we find great deposits of sandstone and shale, of Eocene age, known as the Flysch. It is poor in fossils, but sometimes contains enormous numbers of erratic blocks of granite, gneiss, and other old rocks, which appear to have come from Central Europe. The beds are believed by some geologists to have in part at least a glacial origin.

Oligocene beds of Croatia. The Brown Coal of Radaboj, near Agram, in Croatia, not far from the borders of Styria, is covered, says Von Buch, by beds containing the marine shells of the Vienna basin. The strata correspond in age to the Middle Oligocene of Belgium. They have yielded more than 200 species of fossil plants, described by the late Professor Unger. These plants are well preserved in a hard marlstone, and contain several palms; among them *Sabal* (fig. 193, p. 200), and another genus allied to the date-palm. The only abundant plant among the Radaboj fossils which is characteristic of the Miocene period is the *Populus mutabilis*, Heer, whereas no less than fifty of the Radaboj species are common to the more ancient flora of the Lower Molasse or Oligocene of Switzerland.

The insect fauna is very rich,

and, like the plants, indicates a more tropical climate than do the fossils of Oeningen already mentioned. There are ten species of *Termites*, or White ants, some of gigantic size, and large dragon-flies with speckled wings, like those of the Southern States in North America; there are also grasshoppers of considerable size, and even the Lepidoptera are not unrepresented. (See fig. 197, p. 201.)

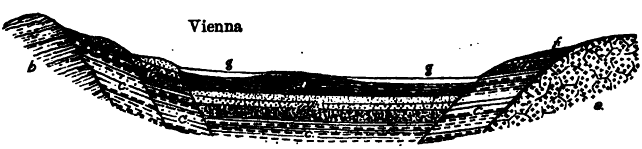
In the Vienna basin we find strata possibly as old as the Upper Oligocene, with *Cerithium plicatum*, Lam., in the marine layers and *Melania* in the freshwater deposits.

Miocene beds of the Vienna basin.—In South Germany the general resemblance of the Vienna basin the remains of several mammalia have been found, and among them a species of *Dinotherium*, a Mastodon of the *Trilophodon* division, a Rhinoceros (allied to *R. megarhinus*, Christol), also an animal of the hog tribe, (*Listriodon*, Von Meyer), and a carnivorous animal of the canine family. The *Helix turonensis*, Desh. (fig. 58, p. 56), the most common terrestrial shell of the French faluns, accompanies the above land animals.

The flora of the Vienna basin exhibits some species which have a general range through the whole Miocene period.

There are two main divisions in the Miocene tertiaries of the great area called the Vienna basin.

Fig. 261.



Diagrammatic Section through the Vienna Basin. (After Karrer and Kayser.)

a. Crystalline rocks of the Leitha Mountains. *b.* Flysch (Eocene) of the Vienna Hills. *c.* Marine Miocene (Mediterranean series). *d.* Brackish-water, Upper Miocene (Sarmatian series). *e.* Pliocene (Congeria Beds). *f.* Drift. *g.* Alluvium.

the shells of the Vienna tertiary basin to those of the faluns of Touraine has long been acknowledged.

According to Professor Suess, the most ancient and purely marine of the Miocene strata in this basin consist of sands, conglomerates, limestones, and clays, and they are inclined inwards, or from the borders of the trough towards the centre, their outcropping edges rising much higher than the newer beds, whether Miocene or Pliocene, which overlie them, and which occupy a smaller area at an inferior elevation above the sea. Dr. Hörnes has described no less than 500 species of Gastropoda, of which he identifies one-fifth with living species of the Mediterranean, Indian, or African seas. In the lowest marine beds of

Sandstones, limestones, and clays, with *Cerithia*, and vast quantities of a few species of *Tapes*, *Mactra*, *Murex*, &c. Corals and Bryozoa are rare. This Sarmatian division covers a marine group with limestones crowded with corals—the Leithakalk—which was deposited at a period when a subtropical climate prevailed.

Pliocene strata of the Vienna basin.—The Congerian strata, which contain vast numbers of *Congeria subglobosa*, Partsch, are sands with the bones of large animals overlying a clay of 800 feet in thickness. The fossils indicate Caspian conditions, rather than those of an open sea, and show that there was an inland gulf, with its water gradually becoming brackish and fresh.

As might be expected, deposits

of rock-salt, gypsum, and anhydrite occur in this formation, the result of evaporation of the old sea. The mammalia belonged to the genera *Dinotherium*, *Mastodon*, *Acerotherium*, *Rhinoceros*, *Hippotherium*, *Machairodus*, *Hyæna*, *Cervus*, and *Antilope*. The flora includes conifers of the genera *Sequoia*, *Pinus*, *Glyptostrobus*; with dicotyledons, like the Birch, Alder, Oak, Beech, Chestnut, Hornbeam, *Liquidambar*, Plane, Laurel, *Cinnamon*, and forms referred to the Asiatic genus *Parrotia*, and the Australian *Hakea*.

Older Pliocene formations of Greece.—At Pikermi, near Athens, Wagner and Roth have described a deposit in which they found the remains of a splendid fauna. This fauna attests the former extension of a vast expanse of grassy plains, where we have now the broken and mountainous country of Greece; and these plains were probably united with Asia Minor, spreading over the area where the deep Ægean Sea and its numerous islands are now situated, and extending into Africa. We are indebted to Gaudry for a treatise on the fossil bones of Pikermi, showing how many data they contribute to the theory of a transition from the mammalia of the Pliocene and Pleistocene to those of living genera and species. For example, he recognised such synthetic types as an Ape (*Mesopithecus*) intermediate between the living genera *Semnopithecus* and *Macacus*; a carnivore intermediate between the hyæna and the civet; a pachyderm (*Hipparion*) intermediate between the *Anchitherium* and the horse: and a ruminant intermediate between the goat and the antilope. The Carnivora belong to the genera *Machairodus*, several species of *Felis*, *Hyæna*, *Hyænictis*, *Limnocyon*, *Mustela*, *Ictitherium*, *Promephitis*; Rodents, *Hystrix*; Edentata, *Ancylotherium*; Proboscidæa, *Mastodon*, *Dinotherium*; Perissodactyla, several species of *Rhinoceros*, *Acerotherium*, *Leptodon*, *Hipparion*; Artiodactyla, *Sus*, *Camelopardalis*, *Helladotherium*, *Antilope*, *Gazelle*, *Palæoryx*, *Palæoreas*, *Dromotherium*. A turtle, a Saurian, birds of the pheasant tribe, and a crane have also been found. This remarkable assemblage is characterised by a strong African element.

CAINOZOIC STRATA OF INDIA

Eocene, Oligocene, and Miocene of India.—In Sind we find strata of Miocene age resting upon an important Oligocene series called the Nari series, which contains a characteristic fauna of reef-building corals, and very flat Echinolampads, with a few Nummulites. The Oligocene strata rest on the Nummulitic.

Pliocene of India.—In the Sind area, the succession of Eocene, Oligocene, and Miocene marine strata is covered by freshwater and terrestrial deposits of great thickness, called Manchhar beds. These last are the geological equivalents of the conglomerates, sands, marls, and gravels which flank the Himalayas on the south, and which are called the Siválik strata. The latter are terrestrial and freshwater deposits, and are the results of the denudation of the country during the time when the Himalayas gradually rose into a great mountain mass.

In the Manchhars the following genera of Vertebrata have been discovered:—*Amphicyon*, a carnivore; Proboscidæa, *Mastodon* (three species), *Dinotherium*; Perissodactyla, *Rhinoceros*, *Acerotherium*; Artiodactyla, *Sus*, *Hemimeryx*, *Sivameryx*, *Chalicotherium*, *Anthracotherium*, *Hyopotamus*, *Hyotherium*, *Dorcotherium*; Edentata, *Manis*; Reptilia, *Crocodilus*, Chelonia, Ophidia, &c.

The mollusca of the Siválik strata, now that the recent forms of India have been studied, turn out to be identical with living forms, or to be closely allied. The genera of Vertebrata are—Quadrumana, *Macacus*, *Semnopithecus*; Carnivora, *Felis*, *Machairodus*, *Pseudaleurus*, *Ictitherium*, *Hyæna*, *Canis*

(*vulpes*), *Amphicyon*, *Ursus*, *Hyænarctus*, *Mellivora* (*meles*), *Lutra*, *Enhydriodon*; Proboscidæa, *Elephas*, *Mastodon*; Perissodactyla, *Rhinoceros*, *Acerotherium*, *Listriodon*, *Equus*, *Hipparion*; Artiodactyla, *Hippopotamus*, *Hippopotamodon*, *Tetrocondon*, *Sus*, *Hippohyus*, *Chalicotherium*, *Merycopotamus*, *Cervus*, *Dorcatherium*, *Camelopardalis*, *Sivatherium*, *Hydaspitherium*, *Bos*, *Bison*, *Bubalus*, *Peribos*, *Amphibos*, *Hemibos*, *Antilope*, *Capra*, *Ovis*, *Camelus*; Rodentia, *Rhizomys*, *Hystrix*; Reptilia, *Crocodilus*, *Ghavialis*, *Emys*, *Colossochelys*.

Some of the Sivâlik fauna lived on during the Pleistocene age, and their remains have been found in the river gravels of the Nerbudda and Godâveri, accompanied by implements of man's making.

POST-PLIOCENE DEPOSITS OF NORTHERN EUROPE AND THE ALPINE DISTRICTS

Post-Pliocene deposits of glacial origin, more or less similar to those of Western Europe, which we have described, are found all over Northern and Central Europe, and even in the mountainous parts of the south of the continent.

As far south as the Hartz Mountains and the Riesengebirge we find masses of boulder-clay and glacial sands, of varying thickness up to 400 feet. They are full of erratic blocks of granite, gneiss, and other rocks, some of which can be identified as having come from Scandinavia, while others are of more local origin. On the mountains of Central Europe these erratic blocks are sometimes found at heights of from 1,200 to 1,500 feet. The rocks on which these glacial deposits lie are often much striated; they present great potholes ('giant kettles') formed by glacier mills, and there are easily recognisable moraines which are of great length and height. Beds of clay and sand containing marine shells, sometimes of very arctic character (*Yoldia* or *Leda* clays), are found, with others containing more temperate forms which are believed to represent pre-glacial or interglacial deposits. The German geologists classify their Post-Pliocene deposits as follows:—

Post-Glacial.—Upper sands.

Newer Glacial.—Upper Boulder Clay (yellow).

Interglacial.—Middle sands (with mammalian remains), containing intercalated bands of calcareous tufa.

Older Glacial.—Lower Boulder Clay (blue).

Pre-Glacial.—Stratified Sands and Clays, sometimes containing marine shells.

The Glacial Deposits of Scandinavia and Russia.—In large tracts of Norway and Sweden, where there have been no glaciers in historical times, the signs of ice-action have been traced as high as 6,000 feet above the level of the sea. These signs consist chiefly of polished and furrowed rock-surfaces, of moraines and erratic blocks. The direction of the erratics, like that of the furrows, has usually been conformable to the course of the principal valleys; but the lines of both sometimes radiate outwards in all directions from the highest land, in a manner which is only explicable by the hypothesis of a general envelope of continental ice, like that of Greenland. Some of the far-transported blocks have been carried from the central parts of Scandinavia towards the Polar regions; others southwards to Denmark; some south-westwards, to the coast of Norfolk in England; other south-eastwards, to Germany.

In the immediate neighbourhood of Upsala, in Sweden, there occurs a ridge of stratified sand and gravel, in the midst of which occurs a layer of marl, evidently formed originally at the bottom of the Baltic, and containing the mussel, cockle, and other marine shells of living species, intermixed

with some proper to fresh water. The marine shells are all of dwarfish size, like those now inhabiting the brackish waters of the Baltic; and the marl, in which many of them are embedded, is raised more than 100 feet above the present level of the Gulf of Bothnia. Upon the top of this ridge repose several huge erratics, consisting of gneiss, for the most part unrounded, from 9 to 16 feet in diameter, which must have been brought into their present position since the time when the neighbouring gulf was already characterised by its peculiar fauna. Here, therefore, we have proof that the transport of erratics continued to take place, not merely when the sea was inhabited by the existing mollusca, but when the North of Europe had already assumed that remarkable feature of its physical geography which separates the Baltic from the North Sea, and causes the Gulf of Bothnia to have only one-fourth of the saltness belonging to the ocean. In Denmark, also, recent shells have been found in stratified beds, closely associated with the boulder clay.

The geologists of Sweden and Norway have classified their Post-Pliocene deposits as follows:—

Post-Glacial.—Bedded sands formed during the retreat of the glaciers.

Newer Glacial.—Upper Boulder Clay (yellow).

Interglacial. — Bedded sands and clays with remains of the dwarf birch, &c., best seen in Scania, Southern Sweden.

Older Glacial.—Lower Boulder Clay (blue).

The Åsar, corresponding to our eskers or kames, are great ridges composed of sand and pebbles, which run, often in sinuous lines, across the country for many miles, and are sometimes more than 100 feet in height. By some authors they are regarded as being moraines, by others as being accumulated by the waters flowing from the ice-sheets during their retreat.

Drift Deposits of Mountain Districts.—In the higher regions of mountains, where the amount of snow that falls in winter so far exceeds the loss in summer, through melting and evaporation, an indefinite thickness would accumulate if it were not prevented by the formation of névé. This becoming gradually converted into ice, the glaciers are fed, and they glide down the principal valleys. On the glaciers' surface, are seen long lines or heaps of sand and mud, with angular fragments of rock, which fall in quantities from the steep slopes or precipices on either side, where the rocks are daily exposed to great changes of temperature. These deposits, being arranged along the sides of the glacier, are termed *lateral moraines*. When two glaciers meet, unite, and continue their course, the right lateral moraine of the one and the left of the other meet together in the centre of the joint glacier, forming what is called a *medial moraine*. These surface moraines finally fall, or are dropped at the lower end or foot of the glacier, and form the *terminal moraine*.

Besides the blocks thus carried down on the top of the glacier, many fall, through fissures in the ice, to the bottom, where some of them become firmly frozen into the mass, and are pushed along the base of the glacier, abrading, polishing, and grooving the rocky floor below, as a diamond cuts glass, or as emery powder polishes steel, and the larger blocks are reciprocally grooved and polished by the rocky floor on their lower sides. Stones which have been frozen into the bottom of the glacier scratch the adjacent rocks, producing long striæ. The striæ and the deep grooves thus made are rectilinear and parallel to an extent never seen in those produced on loose stones or rocks, where shingle is hurried along by a torrent, or by the waves on a sea-beach. At the same time a stream of water, produced by the melting of the ice, issues from beneath the glacier charged with mud, derived, not only from the atmospheric waste of the rocks above, but in part also from the crushing of the fragments of stone, which have reached the bottom of

the glacier, and the abrasion of its rocky floor.

In addition to these polished, striated, and grooved surfaces of rock, another proof of the former action of a glacier is afforded by the 'roches moutonnées,' or projecting eminences of rock which have been smoothed and worn into the shape of flattened domes by the glacier as it passed over them. They have been traced in the Alps to great heights above the present glaciers, and also to great distances below and beyond them. If the glacier is greatly diminished by melting, large angular fragments, which are called 'perched blocks,' are left behind.

Alpine blocks on the Jura.—The moraines, erratics, polished surfaces, domes, perched blocks, and striæ, above described, are observed in the great valley of Switzerland, fifty miles broad; and on the Jura, a chain which lies to the north of this valley. The average height of the Jura is about one-third that of the Alps, and it is now entirely destitute of glaciers; yet it also presents moraines, and polished and grooved surfaces. The erratics, moreover, which are upon it even to a height of 2,500 feet, present a phenomenon which has astonished and perplexed the geologist for nearly a century. No conclusion can be more incontestable than that these angular blocks of gneiss and other crystalline formations came from the Alps, and that they have been brought for a distance of fifty miles and upwards, across a wide and deep valley; so that they are now lodged on hills composed of sedimentary formations. The great size and angularity which the blocks retained, after a journey of so many leagues, has justly excited wonder; for many of them are as large as cottages; and one in particular, composed of gneiss, celebrated under the name of Pierre à Bot, rests on the side of a hill about 900 feet above the Lake of Neufchâtel, and is no less than 40 feet in diameter.

The manner in which these erratics were conveyed from the Alps to the Jura was formerly the subject of considerable controversy. Venetz proved that the Alpine glaciers must formerly have extended far beyond their present limits, and it was argued that the blocks now found on the Jura had been transported by their agency. Other writers, on the contrary, conjectured that the whole country had been submerged, and that the moraines and erratic blocks must have been transported by floating icebergs, as it was held that the difference in height between the two mountain ranges was not sufficient to have allowed the glaciers to flow from the Alps across the wide valley to the Jura. But the definite order in which the Alpine erratics are arranged, and the total absence of marine shells, have gone far to disprove this last hypothesis. Besides, we have no right to assume that the relative heights of the Alps and Jura have remained unaltered since the era of the transportation of the erratics; still less that the change of level which last took place was uniform over a great district, either in amount or direction.

The Palæolithic Period in Western Europe.—Of post-glacial deposits with the remains of man we find many examples in Southern Europe. River-gravels and peat-deposits, like those already described in France and Denmark, occur in Switzerland, Italy, and Southern Germany. Many of these seem to be only a little younger than the glacial formations, while certain deposits containing human relics are believed by some geologists to be inter-glacial or even pre-glacial in age.

On the other hand we have interesting remains in the South of France of a race of men, which, though certainly pre-historic, was younger than the race of which the relics are found in most of our river-gravels and caverns when the mammoth abounded, though this animal, as we shall see, had not entirely disappeared from Southern Europe during the later of the Palæolithic periods.

Newer Palæolithic Age—Reindeer Period.—There are

some caves in the departments of Dordogne, Aude, and other parts of the South of France, the contents of which accumulated late in the Palæolithic period. They are said to belong to the 'reindeer-period,' because vast quantities of the bones and horns of that deer have been met with. In some cases separate plates of molars of the mammoth, and several teeth of the great Irish deer, *Cervus Megaceros*, Hart., and of the cave-lion, *Felis spelæa*, Goldf., an extinct variety of *Felis leo*, L., have been found mixed up with cut and carved antlers of reindeer. On one of these sculptured bones in the cave of Périgord, a rude representation of the mammoth, with its long curved tusks and long hair and covering of wool, occurs; and this is regarded by M. Lartet as placing beyond all doubt the fact that the early inhabitants of these caves must have seen this species of elephant still living in France. The presence of the remains of the marmot, as well as reindeer and some other northern animals, in these caverns seems to imply a colder climate than that of the Swiss lake-dwellings, in which no remains of reindeer have as yet been discovered. The absence of this animal in the old lacustrine habitations of Switzerland is the more significant, because in a cave in the neighbourhood of the Lake of Geneva, namely, that of Mont Salève, bones of the reindeer occur with flint-implements similar to those of the caverns of Dordogne and Périgord.

The state of the arts, as exemplified by the instruments found in these caverns of the reindeer period, is much more advanced than that which characterises the tools of the Amiens drift, but is nevertheless more rude than that of the Swiss lake-dwellings. No metallic articles occur, and the stone-hatchets are not ground after the fashion of celts; the needles of bone are shaped in a workmanlike style, having their eyes drilled with skill.

The formations above alluded to, which are as yet but imperfectly known, may be classed as belonging to the close of the Palæolithic era.

The Lacustrine Habitations of Switzerland, Neolithic and Bronze Periods.— The pile dwellings of the Swiss lakes appear to belong to a somewhat later time even than the Newer Palæolithic (reindeer period) of the South of France. They have been known to geologists and archæologists since 1854, in which year Dr. F. Keller explored near the shore at Meilen, in the bottom of the lake of Zurich, the ruins of an old village, originally built on numerous wooden piles, driven, at some unknown period, into the muddy bed of the lake. Since then, in very many other localities, vestiges and more or less perfect foundations of similar pile-dwellings have been found near the borders of the Swiss lakes, at points where the depth of water does not exceed 15 feet. The superficial mud in such cases is filled with various articles, many hundreds of them being often dredged up from a very limited area. Thousands of piles, decayed at their upper extremities, are often met with still firmly fixed in the mud.

As the ages of polished stone, bronze, and iron merely indicate successive stages of civilisation, they may all have coexisted at once in different parts of the globe, and even in contiguous regions, among nations having little intercourse with each other. To make out, therefore, a distinct chronological series of monuments is only possible when our observations are confined to a limited district, such as Switzerland.

The relative antiquity of the pile-dwellings, which belong respectively to the ages of polished stone and bronze, is clearly illustrated by the association of the tools with certain groups of animal remains. Where the tools are of stone, the castaway bones which served for the food of the ancient people are those of deer, the wild boar, and wild ox, which abounded when society was in the hunter state. But the bones of the later or bronze epoch were chiefly those of the

domestic ox, goat, and pig, indicating progress in civilisation. None of the great mammalia or the commonest animals of the antecedent period are found preserved. Some villages of the polished stone age are of later date than others, and exhibit signs of an improved state of the arts. Among other relics, are discovered carbonised grains of wheat and barley, and pieces of bread, proving that the cultivation of cereals had begun. In the same settlements, also, cloth, made of woven flax and straw, has been detected.

The pottery of the bronze age in Switzerland is of a finer texture, and more elegant in form, than that of the age of stone. At Nidau, on the Lake of Bienne, articles of iron have also been discovered, so that this settlement was evidently not abandoned till that metal had come into use.

At La Thène, in the northern angle of the Lake Neufchâtel, a great many articles of iron have been obtained, which in form and ornamentation are entirely different both from those of the bronze period and from those used by the Romans. Coins, which sometimes occur in deposits of the age of iron, have never been found in the deposits of the ages of bronze or stone.

The manufacture of bronze was very general over Europe and Asia, and as tin, which enters into this metallic mixture in the proportion of about 10 per cent. to the copper, was not a common metal, and was not found everywhere, commerce must have existed. It is known that Cornwall was traded with late in the age. Very few human bones of the bronze period have been met with in the Danish peat, or in the Swiss lake-dwellings, and this scarcity is generally attributed by archæologists to the custom of burning the dead, which prevailed in the age of bronze.

POST-PLIOCENE DEPOSITS IN OTHER PARTS OF THE EASTERN HEMISPHERE

India.—We find in the Himalayas evidence that the glaciers of that mountain range, like those of the Alps, once extended to far lower levels than they do at present. Great moraines with striated surfaces, perched blocks, and other indications of the action of ice, can often be traced many thousands of feet below the points now reached by the existing glaciers.

New Zealand and Australia.—In these countries somewhat conflicting statements have been made by different observers as to the existence of the glacial period. But even if undoubted evidence of glacial conditions were forthcoming, it would not be safe to infer that the glacial period was contemporaneous with that occurring in this country and North America. Some writers, indeed, incline to the view that glacial periods must necessarily occur at different times in the Northern and Southern hemispheres.

Australian cave-breccias. Ossiferous breccias are not confined to Europe, but occur in many other parts of the globe where there are limestone rocks; and those discovered in fissures and caverns in Australia correspond closely in character with those of Europe, but not in their organic remains.

Some of these caves in the Wellington Valley, New South Wales, were examined by the late Sir T. Mitchell, and the breccia contained a great accumulation of bones of animals, none of which have been found beyond the Australian province.

CAINOZOIC STRATA OF NORTH AMERICA

Eocene strata in the United States.—In Eastern North America the Eocene formations occupy a large area bordering the Atlantic, which increases in breadth and importance as it is

traced southwards from Delaware and Maryland to Georgia and Alabama. They also occur in Louisiana and other States both east and west of the valley of the Mississippi. At Claiborne, in Alabama, no less than 400 species of marine shells, with many echinoderms and teeth of fish, characterise one member of this system. Among the shells, the *Cardita planicosta*, Lam., before mentioned (fig. 228, p. 209), is in abundance; and this fossil and some others identical with European species, or very nearly allied to them, make it highly probable that the Claiborne beds agree in age with the Upper Eocene or Bracklesham group of England, and with the Calcaire grossier of Paris.

Higher in the series is a remarkable calcareous rock, made up of Foraminifera, called Orbitoidal limestone.

Above the Orbitoidal limestone is a white limestone, sometimes soft and argillaceous, but in parts very compact and calcareous. It contains several peculiar corals, and a large Nautilus allied to *N.* (*Aturia*) *ziczac*, Sow.; also in its upper bed the gigantic Cetacean, *Zeuglodon* (fig. 191, p. 199).

The colossal bones of this Cetacean are so plentiful in the interior of Clarke County, Alabama, as to be characteristic of the formation. The vertebral column of one skeleton extended to the length of nearly seventy feet, and not far off part of another backbone, nearly fifty feet long, was dug up.

Eocene of the Western Territories.—There is some difficulty in determining the base of the Eocene series in the Western Territories of the United States in consequence of the different conclusions that have been drawn from the study of the mammalian and plant remains. But there is a limit drawn by the distinguished American palæontologist, Professor Marsh, who writes: 'The line, if line there be, separating the Cretaceous from the Tertiary, must at present be where the Dinosaurs and other Mesozoic vertebrates disappear and are replaced by the Mammals, henceforth the dominant type.'

The freshwater Eocene deposits are between the Rocky Mountains and the Wahsatch range to the west, and are on the central plateau of the continent. The area was marine during the older Cretaceous period; elevation taking place subsequently, the salt-water deposits gave place to freshwater ones, which accumulated in lakes surrounded by a land teeming with life and luxuriant vegetation. The lacustrine deposits are at least two miles in thickness, and form three groups with different faunas.

The Lower Eocene.—This rests unconformably on the Cretaceous, and has been called the Vermilion Creek or Wahsatch group. It contains a well-marked mammalian fauna, including *Coryphodon*, a Tapir-like animal, with low cerebral characteristics. The occurrence of other species of this genus in Europe at the same geological horizon is very remarkable. A diminutive ancestor of the horse, *Eohippus*, of the size of a Fox, and an equally small Tapir, are characteristic of the deposits, as is the genus *Limnohyus*, and the earliest Pig, *Eohyus*. *Dryptodon* belongs to the family Tillodontia, which combines the characters of several mammalian groups, such as the ungulates, carnivora, and rodentia. The oldest Squirrel, *Sciuravus*, and the earliest carnivora, *Limnocyon* and *Prototomus*, occur, and the genera *Lemuravus* and *Limnotherium*, which were lemurine animals.

The Middle Eocene.—The Green river and Bridger series are characterised by the presence of *Dinocerata*, a family of gigantic Ungulates. A number of species of *Dinoceras*, *Tinoceras* (fig. 190, p. 198), &c., lived during the Middle Eocene, and disappeared before the close of the period. They nearly equalled the Elephants in bulk, and the skull had two or three pairs of horns and enormous canine tusks. The brain was exceedingly small. *Orohippus*, a more advanced horse; a Tapir with horns, *Colonocerus*; a huge

Tapiroid, *Palæosyops*; *Helohyus*, a Pig-like animal with four toes; and *Homocodon*, a crescent-toothed ruminant; with *Tillotherium*, occur. Small rodents of extinct genera and Insectivora were numerous. Carnivora increased in number, and *Limnofelis* was as large as a Lion; *Orocyon* had massive jaws and short teeth; and *Dromocyon* was also a large animal. The Lemuroid genera persisted, and *Limnotherium* had affinities with the Marmosets. The oldest Rhinoceros of America was *Orthocynodon* of these beds.

The Upper Eocene.—The Uinta group is characterised by a large Mammal, the *Diplacodon*, and an odd-toed Ungulate, *Orohippus*, still lived on, and became extinct during this age. One of the Rhinocerotidæ was *Amynodon*. The crescent-toothed Ungulates are small, and *Eomeryx* is allied to *Hyopotamus* of Europe, and *Oromeryx* has affinities with the Deer, which appeared subsequently. This wonderful Eocene fauna contains no species of *Anoplotherium* or *Palæotherium*, European Eocene forms, or of any Proboscidean, Edentate, or Hollow-horned Ruminant. But the Rhinoceros, Horse, Pig, Deer, and Tapir were clearly foreshadowed. It appears that as the Carnivora increased in numbers, the huge horned animals gradually disappeared.

The Lower Eocene contained *Crocodilia*, Wading birds, and *Unitornis*, a Wood-pecker. Large serpents occurred during the Eocene, and were related to the *Boa constrictor*, L. Lizards were numerous, and the modern Gar-pike and a Dog-fish were represented by closely allied species.

The Oligocene and Miocene of the Western Territories of the United States.—The Miocene deposits are those of ancient lake-basins on the flanks of the high central plateau of North America. The fauna is divisible into three groups, and it is probable, as shown by Professor Scott, that the lowest corresponds with the European Oligocene. This lowest group is only found on the east of the Rocky Mountains, and is characterised by the peculiar mammals termed Brontotheridæ. These were perissodactyles with affinities with the Tapirs. *Brontotherium* was as large as an elephant. The limbs were short, the tail was long, and the nose probably flexible. A pair of horn cores existed upon the maxillary bones in front of the orbits, and the brain cavity was small. *Mesohippus*, as large as a sheep, is a representative of the horse, and is a transitional form between the Eocene *Eohippus* and the late Pliocene *Equus*, the intermediate forms being *Miohippus* of the Upper Miocene, and *Protohippus* of the Pliocene (fig. 162, p. 178). *Dicerotherium*, allied to *Rhinoceros*, also existed at this period. *Perchœrus* and *Elotherium* were the great pigs of the day, and some equalled *Rhinoceros* in dimensions. *Hyopotamus* was a crescent-toothed, even-toed creature. *Poebrotherium*, allied to the Camel, *Leptomeryx* to the Deer, occur; but the hollow-horned ruminants had not yet appeared, nor had the Proboscideans. *Hyænodon* was a carnivore, and Insectivora lived in those days.

The Lower Miocene, on both sides of the Rocky Mountains, is characterised by ruminating pigs of the genera *Oreodon* and *Eporeodon*, which were larger than the Peccary. The *Leporidæ*, or hare family, lived in considerable numbers; and other Rodentia of the Squirrel, Mouse, and Beaver families, were represented by genera now extinct. *Machairodus* occurs; and *Laopithecus*, one of the Monkey tribe, with South American affinities. The Upper Miocene, which occurs in Oregon, is of great thickness, and the characteristic genus is *Miohippus*, already noticed. *Hyracodon*, *Dicerotherium*, and *Acerotherium* were Rhinocerotidea of the period, and *Chalicotherium* was a genus which is also found fossil in Europe and in the Himalayan area. Besides these forms, there were *Moropus*, a large Edentate, *Tinohyus*, an ally of the Peccary, and *Allomys*, related to the flying Squirrels.

Neocene of the United States.—Between the Alleghany Mountains, formed of older rocks, and the Atlantic, there intervenes a low region occupied principally by beds of marl, clay, and sand, consisting of the Cretaceous and Tertiary formations, and chiefly of the latter. It consists, in the south, as in Georgia, Alabama, and South Carolina, almost exclusively of Eocene deposits; but in North Carolina, Maryland, Virginia, and Delaware more modern strata predominate, of the age of the English crag and the faluns of Touraine.

In the Virginian sands we find in great abundance a species of Astarte (*A. undulata*, Conrad), which resembles closely one of the commonest fossils of the Suffolk Crag (*A. Omalii*, Laj.); the other

Fig. 262.

Astrangia lineata, Lonsdale.. Syn. *Cœnangia*. Williamsburg, Virginia.

shells also, of the genera *Natica*, *Fissurella*, *Artemis*, *Lucina*, *Chama*, *Pectunculus*, and *Pecten*, are analogous to shells both of the English Crag and French faluns, although the species are almost all distinct. Out of 147 of these American fossils only thirteen species are common to Europe, and these occur partly in the Suffolk Crag, and partly in the faluns of Touraine; but it is an important characteristic of the American group, that it not only contains many peculiar extinct forms, such as *Fusus quadricostatus*, Say (see fig. 157, p. 176), and *Venus tridacnoides*, Lam., abundant in these same formations, but also some shells, which, like *Fulgur Carica*, Say, and *F. canaliculatus*, L. sp. (see fig. 156, p. 176), *Calyptræa costata*, Conrad, *Venus mercenaria*, Lam., *Modiola glandula*, Totten, and *Pecten magellanicus*, Lam., are recent species, yet of forms now confined to the Western side of the Atlantic—a fact implying that some traces of the beginning of the present geographical distribution of mollusca date back to a period as remote as that of the Miocene Strata.

In the Carolina States there are from 40 to 60 per cent. of still living species amongst the testacea. Mr. Lonsdale examined the corals and found one agreeing generically with a littoral American form (fig. 262).

Among the remains of fish in these strata are several large teeth of the shark family, not distinguishable specifically from fossils of the faluns of Touraine.

Pliocene of the Western Territories of the United States.—Marsh states that east of the Rocky Mountains and on the Pacific coast, the Pliocene deposits rest unconformably on the Miocene, and that there is a well-marked faunal change, modern types of vertebrata making their appearance. He considers that the division between Miocene and Pliocene in Europe is at a higher geological horizon than in America. A true species of *Equus*, not found in the Miocene, characterises the Pliocene of America. No Marsupials are found in the Pliocene deposits; but large Edentata occur in the Lower Pliocene, the genera being *Morotherium*, and possibly *Moropus*. The migration of Edentata was probably from north to south, and the Post-Pliocene Edentata of North America are of the same genera as those of South America—*Megatherium*, *Mylodon*, and *Megalonyx*. Amongst the Equine group, *Protohippus*, with three toes to each foot, was as large as an ass; and *Pliohippus* is without the extra toe, and is a true horse. *Equus* is present, but became extinct, for no horses were found by the first colonists of America from Europe. *Diceratherium* and other large Rhi-

noceridæ occur, and all became extinct before the Post-Pliocene. The genus *Tapirus* is found in the Post-Tertiary deposits, and probably existed during the Pliocene.

All the members of the pig tribe in the Pliocene are closely related to the Peccaries, and no true pig or *Hippopotamus* has been found. The ruminating hogs existed, and there were the genera *Merychochærus* and *Merychyus*, but they became extinct at the close of the period. Deer and bison occur, but no sheep or goats.

Mastodon appears in the Lower Pliocene, and lived on into the Pleistocene, and *Elephas* came in with the Newer Pliocene. Among the Carnivora the genera *Canis*, *Machairodus*, *Leptarctus*, and *Ursus* are represented. No remains of Primates have been found, however.

In the Upper Missouri region there are freshwater beds—the Loup-River group of Meek and Hayden or Niobara of Marsh, containing many vertebrate remains of the genera *Mastodon*, *Elephas*, *Rhinoceros*, *Felis*, *Procamelus*, *Homocamelus*, *Protohippus*, and *Equus*.

The Californian auriferous gravels of the Sierra Nevada, capped by basalt, are probably of this age.

Post-Pliocene Formations in North America.—In the western hemisphere, both in Canada and as far south as the 40th and even the 38th parallel of latitude in the United States, we meet with a repetition of all the peculiarities which distinguish the European Boulder-clay formation. Fragments of rock have travelled for great distances, especially from north to south; the surface of the subjacent rock is smoothed, striated, and grooved; unstratified mud or *till* containing boulders is associated with strata of loam, sand, and clay, usually devoid of fossils. Where shells are present, they are of species still living in northern seas, and not a few of them are identical with those belonging to European drift, including most of those already figured, pp. 148–9. The fauna also of the glacial epoch in North America is less rich in species than that now inhabiting the adjacent sea, whether in the Gulf of St. Lawrence, or off the shores of Maine, or in the Bay of Massachusetts.

The extension, on the American continent, of the range of erratics during the Post-Pliocene period, to lower latitudes than in Europe, agrees well with the present southward deflection of the isothermal lines, or rather the lines of equal winter temperature. It seems that formerly, as now, a more extreme climate and a more abundant supply of ice prevailed on the western side of the Atlantic. Another resemblance between the distribution of the drift-fossils in Europe and North America has yet to be pointed out. In Canada and the United States, as in Europe, the marine shells are generally confined to very moderate elevations above the sea (between 100 and 700 feet), while the erratic blocks and the grooved and polished surfaces of rock extend to elevations of several thousand feet.

The rocks which underlie the glacial deposits of North America are iceworn, and striæ are found on them at great elevations. The Catskills, which rise from the plain of the Hudson, are found grooved and striated up to near their summits, or to about 3,000 feet. The White Mountains are ice-worn up to 5,300 feet.

The Champlain series of glacial deposits are unstratified and stratified drifts, and were formed after the boulder-clay. Their lower portion is marine, reaches up the valleys from the coast, and contains *Leda truncata*, Brown, *Saxicava rugosa*, Lam., and *Tellina grœnlandica*, Beck., with bones of seals and whales. Most of the shells, of which one hundred species are known, are Arctic or boreal, and one half are common to the British glacial beds.

Terraces of marine origin occur on the coast and far inland, from 150 to 500 feet. Inland, the terraces often show four or five

platforms, as in the Connecticut Valley.

It has been already mentioned that in Europe several quadrupeds of living, as well as of extinct, species were common to pre-glacial and post-glacial times. In like manner there is reason to suppose, that in North America much of the ancient mammalian fauna, together with nearly all the invertebrata, lived through the ages of intense cold. That *Mastodon giganteus*, Cuv., was very abundant in the United States after the drift period, is evident from the fact that entire skeletons of this animal are met with in bogs and lacustrine deposits occupying hollows in the glacial drift. They sometimes occur in the bottom even of small ponds recently drained by the agriculturist for the sake of the shell-marl. In 1845 no less than six skeletons of the same species of Mastodon were found in Warren County, New Jersey, six feet below the surface.

It would be rash, however, to infer from such data that these quadrupeds were mired in *modern* times, unless we use that term strictly in a geological sense. It has been shown that there is a fluviatile deposit in the valley of the Niagara, containing shells of the genera *Melania*, *Limnæa*, *Planorbis*, *Valvata*, *Cyclas*, *Unio*, *Helix*, &c., all of recent species. From this deposit the bones of the great Mastodon have been taken in a very perfect state. Yet the whole excavation of the ravine, for many miles below the Falls, has been slowly effected since that fluviatile deposit was thrown down. Other extinct animals accompany the *Mastodon giganteus*, Cuv., in the post-glacial deposits of the United States, and this, taken with the fact that so few of the mollusca, even of the commencement of the cold period, differ from species now living, is important, as refuting the hypothesis, for which some have contended, that the intensity of the glacial cold annihilated all the species in temperate and Arctic latitudes.

European geologists and palæontologists have given a great number of names to the minor subdivisions of the Cainozoic Era; among the principal of which are the following:—

Among Pleistocene deposits the following divisions are recognised:—

Iron and Bronze Ages.

Neolithic, or period of polished stone implements.

Newer Palæolithic, including the *Chellean*, Reindeer Period, and *Mousterian* of Mortillet.

Older Palæolithic, including the *Solutrean* or Mammoth Period, and *Magdalenean* of Mortillet.

In the Newer Tertiaries we have, in descending order, the following:—

Sicilian, including the younger Pliocenes of Sicily and the Val d'Arno, and our Forest-bed series.

Astian, including the Subapennines of Tuscany, and our Norwich and Red Crags and the Scaldisian of Belgium.

Plaisancian, including the Lower Subapennines of Tuscany, the White Crag of England, and the Diestien or Black Crag of Antwerp.

Pontian (or Congerian beds), including the lowest Subapennines of Sicily and Tuscany, and the highest Neogene of Eastern Europe.

Sarmatian, including Marls and Cerithium beds of Austria and Italy.

Messinian (or Zanclean) of Southern Italy and Sicily, both marine and brackish-water in origin, with 83 per cent. of recent mollusca.
Tortonian (or Newer Mediterranean ?), including the Leitha limestones and associated beds of the Vienna basin, and the Oeningen strata of Switzerland, the equivalents of the Anversian and Bolderian of Belgium.
Helvetian (or Lower Mediterranean ?), including the Faluns of Touraine, the Marine Molasse of Switzerland, the Superga beds of North Italy, and the Older Neogene of the Vienna basin.
Burdigalian, including the lower Freshwater Molasse of Switzerland.

Among the Older Tertiary divisions we have the following :—

Aquitanian, including the Beauce limestone of the Paris basin and the Upper Oligocene.
Tongrian (with the Rupellian), including the Middle Oligocene and our Hempstead and Bembridge beds.
Ludian (or Priabonian), including the marls of Ludes and the sands of Argenteuil, and our Brockenhurst and Headon beds.
Bartonian, including the Barton clay, the Sables de Beauchamp, and the Wemmelian of Belgium.
Parisian (or Lutetian), including the Calcaire grossier and the Bracklesham and Bournemouth beds, with the Belgian strata known as Laekanian, Bruxellian, and Paniselian.
Londonian (or Ypresian), including the London clay and the sands of Alum Bay, with the equivalent strata of Belgium.
Sparmacien, including the Argile plastique and the Upper Landenian of Belgium, and our Woolwich and Reading series.
Thanetian, including the Thanet sands and the Lower Landenian of Belgium.
Montian, including the limestone of Mons, the marls of Meudon, and the marls of Gelinden.

In Professor Prestwich's papers on the various Tertiary Deposits of Britain, already cited, the student will find their equivalents on the Continent very fully discussed. The Geologists' Association has published an admirable account of the strata of the Paris Basin by Messrs. Harris and Burrows. Besides the accounts of the Foreign Tertiary deposits given in the general geological treatises by Professor Prestwich, Sir A. Geikie, Professor de Lapparent, Professor Credner, and Professor Gümbel, and the admirable 'Text-book of Comparative Geology' of Kayser and Lake, very full information concerning the French Tertiaries will be found in the memoirs of Hébert, Gaudry, and other French authors; on the Belgian Tertiaries by Mourlon, on those of Eastern Europe in the treatise of Von Hauer, and on those of North America in Dana's Geology, and the 'Correlation Papers of the U.S. Geol. Surv.' ('Eocene' by W. B. Clark, and 'Neocene' by W. H. Dall and G. D. Harris).

THE MESOZOIC (SECONDARY) ERA

CHAPTER XVI

THE CRETACEOUS SYSTEM

Lapse of time between Eocene and Cretaceous Periods—Classification of Cretaceous strata—Foraminifera, Sponges, Corals, Bryozoa and Mollusca of the Cretaceous Period—Terrestrial Floras of the Cretaceous—Reptiles, Birds, and Mammals of the Cretaceous—Chalk and Flint—Zones of the Chalk with their fossils—Chalk Marl—Upper Greensand—Gault—Upper Neocomian—Atherfield Clay—Middle Neocomian—Tealby Series—Lower Neocomian—Speeton Clay—Spilsby Sands—The Wealden Clay and Hastings Sands—Punfield beds.

Nomenclature and classification of the Cretaceous strata.—The uppermost of the Mesozoic systems is called the Cretaceous, from *creta*, the Latin name for that remarkable white, earthy limestone which constitutes an upper member of the group in those parts of Europe where it was first studied. The marked difference between the fossils of the Older Tertiary and the Cretaceous systems has led geologists to conclude that a vast lapse of time must have occurred between the completion of the chalk and the deposition of the first strata of the Eocene in Europe. Measured, indeed, by such a standard—that is to say, by the amount of change in the fauna and flora of the earth effected in the interval—the time between the Cretaceous and Eocene may have been as great as that between the Eocene and the present day. Several deposits, however, have been met with during the course of the last half-century, of an age intermediate between the white chalk and the plastic clays and sands of the Paris and London districts—monuments which have the same kind of interest to a geologist that certain mediæval records excite when we study the history of nations. For both of them throw light on ages of darkness, preceded and followed by others of which the annals are comparatively well known to us. But these newly discovered records do not fill up the wide gap, some of them being closely allied to the Eocene, and others to the Cretaceous type, while none appear, as yet, to possess a marine fauna which may entitle them to hold a perfectly transitional place in the great chronological series.

Among the formations alluded to, the Thanet Sand of Prestwich, which has been sufficiently described in a former chapter, and the Belgian formation, known as the Calcaire grossier de Mons, appears to be on a very low horizon of the Tertiary. On the other hand, the Maestricht and Faxoe limestones, to be hereafter described, are very closely connected with the Chalk, to which also the Pisolitic limestone of France is referable.

The Cretaceous group has generally been divided into an Upper and a Lower series, the Upper called familiarly *the chalk*, and the Lower *the greensands*. But these mineral characters often fail, even when we attempt to follow out the same continuous subdivisions, throughout a small portion of the North of Europe, and are valueless when we desire to apply them to more distant regions. It is only by aid of the organic remains which characterise the successive marine subdivisions of the formation in England and France that we are able to recognise in remote countries, such as the South of Europe, North America and India, the formations which were there, more or less contemporaneously in progress. In the annexed table it will be seen that we have used the term Neocomian for the strata commonly called 'Lower Greensand;' this latter term being peculiarly objectionable because the green grains are an exception to the rule in many of the members of this group, even in districts where it was first studied and named. M. Alcide d'Orbigny proposed terms for the French subdivisions of the Upper Cretaceous series, and these are now so generally used by foreign writers that the student should endeavour to remember their relation to the English equivalents so far as it is possible to make them agree.

The following table shows the general succession of the Cretaceous strata.

UPPER CRETACEOUS.	Danian (absent in England).	Maestricht Beds. Limestones of Faxoe (Denmark) and Scania. Pisolitic Limestones of France.
	Senonian.	Upper White Chalk, Chalk with flints, South of England (with Chalk-rock at its base).
	Turonian.	Middle portion of Chalk (Chalk without flints in South of England), with Melbourn rock at its base.
	Cenomanian.	Lower Grey Chalk, with Totternhoe stone at its base. Chalk Marl, Cambridge Greensand, including the Upper Greensand.
	Albian.	Gault.

LOWER CRETACEOUS OR NEOCOMIAN.	Upper Neocomian (Aptian).	'Lower Greensand' of the South of England with upper part of the Speeton Clay of Yorkshire.
	Middle Neocomian (Urgonian).	Middle Speeton Clay and Tealby series of Lincolnshire.
	Lower Neocomian (Neocomian proper).	Lower Speeton Clay and Spilsby sands of Lincolnshire.

The Middle and Lower Neocomian are represented in the South-west of England by the freshwater strata known as the Wealden.

Characteristics of the Cretaceous fauna and flora.—With the exception of a few of the minute and lowly organised Foraminifera, and perhaps one or two forms among the brachiopoda, it is doubtful whether a single species found in the Cretaceous rocks can be identified as having lived on into the Tertiary. Thus the break between the Mesozoic and the Cainozoic periods is in Western Europe almost complete.

Among the Foraminifera of the Chalk there are, besides actually living species, a great number of forms closely related to the Globigerinæ and other species which go to make up the deep-sea oozes of the existing oceans. With these we find great numbers of siliceous sponges like those of the deep sea, but belonging to extinct genera, *Ventriculites* (fig. 267, p. 256), *Cœloptychium*, &c. In the Lower Cretaceous there occur in addition many forms of the large extinct Calcareous sponges (Pharetrones).

Of corals comparatively few interesting forms occur in the Chalk of Western Europe. In the Alpine Cretaceous (Gosau beds, &c.) such forms are, however, very abundant.

Echinoderms are represented by some sea-urchins of the regular form (*Cidaris*, *Salenia*, &c.) and many characteristic forms of the Irregulares, such as *Micraster* (fig. 269), *Holaster*, *Echinoconus* (fig. 270), *Discoidea* and *Echinocorys* (fig. 268). Among the Crinoids the singular stalkless form *Marsupites* (fig. 271) occurs, and is the last survivor of a very ancient type, while both ordinary and brittle starfish are occasionally found.

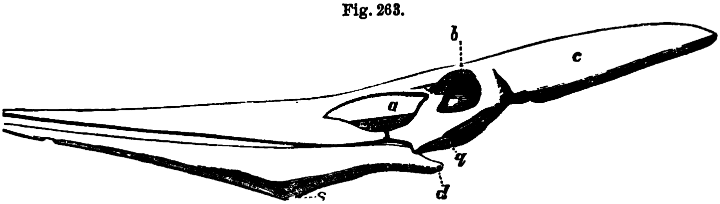
The Bryozoa, which are so abundant in the highest members of the Cretaceous, not found in this country, are not unfrequently found attached to various Chalk-fossils. The Brachiopoda are much more abundant in proportion to the Lamellibranchiata than in the case of any Tertiary deposit. Various forms of Rhynchonellidæ and Terebratulidæ abound, and some forms, like *Lyra* or *Terebrirostra* (fig. 298), *Trigonosemus*, &c., are

peculiar to this system. Among the hingeless forms of Brachiopoda the genus *Crania* (fig. 277) is particularly well represented.

Among the Lamellibranchiata the various forms of *Ostrea* known as *Exogyra* (figs. 280, 296) abound, as do also the varieties of the *Pecten* type called *Janira* or *Neithea* (fig. 299) and also *Inoceramus* (fig. 281) and *Spondylus* (fig. 279). The very abnormal bivalve shells known as *Hippurites*, belonging to the group *Rudistes* and most nearly allied to the *Chama* of the present day, abound in the Alpine Cretaceous, but are also found in small numbers in our Chalk and Neocomian strata (figs. 282–285).

Most of the Gastropoda, so abundant in the Tertiary deposits, are comparatively rare or altogether absent from the Cretaceous rocks of England. But in beds of more littoral origin like those of North Germany and Denmark, Cretaceous Gastropoda are by no means rare.

Fig. 263.



Pteranodon longiceps, Marsh. Skull, 1/12 nat. size. From the Cretaceous of North America.

a. Preorbital vicinity; *b*. orbit; *c*. supraorbital crest; *d*. angle of mandible; *q*. quadrate bone; *s*. symphysis. From a figure by Professor O. C. Marsh.

It is in the forms of the Cephalopods present in the Cretaceous strata that we find the most striking distinction of the marine fauna of the period. Species of the persistent type *Nautilus* (fig. 302, p. 266) are not rare, but are altogether thrown into the shade by the abundant species of Ammonites. These belong to the genera *Hoplites* (fig. 309, p: 268). *Acanthoceras* (fig. 293, p. 262), *Schloenbachia*, *Desmoceras*, &c., and also to the abnormally coiled or uncoiled types *Ancyloceras* (figs. 301, p. 264, and 303, p. 266), *Hamites*, *Scaphites* (fig. 295, p. 262), *Turrilites* (fig. 294, p. 262), *Baculites*, &c. Ordinary *Belemnites*, with other forms known as *Duvallia*, *Belemnitella*, and *Actinocamax*, are also present in great numbers.

Crustaceans of both long-tailed and short-tailed types are by no means rare in the Cretaceous rocks.

The fish of the Cretaceous period include many forms of the ordinary bony fishes (Teleostei), some of which, like *Beryx*, are

closely allied to existing forms. The palatal teeth of forms of Selachians like *Ptychodus* (fig. 289, p. 260) are also very common.

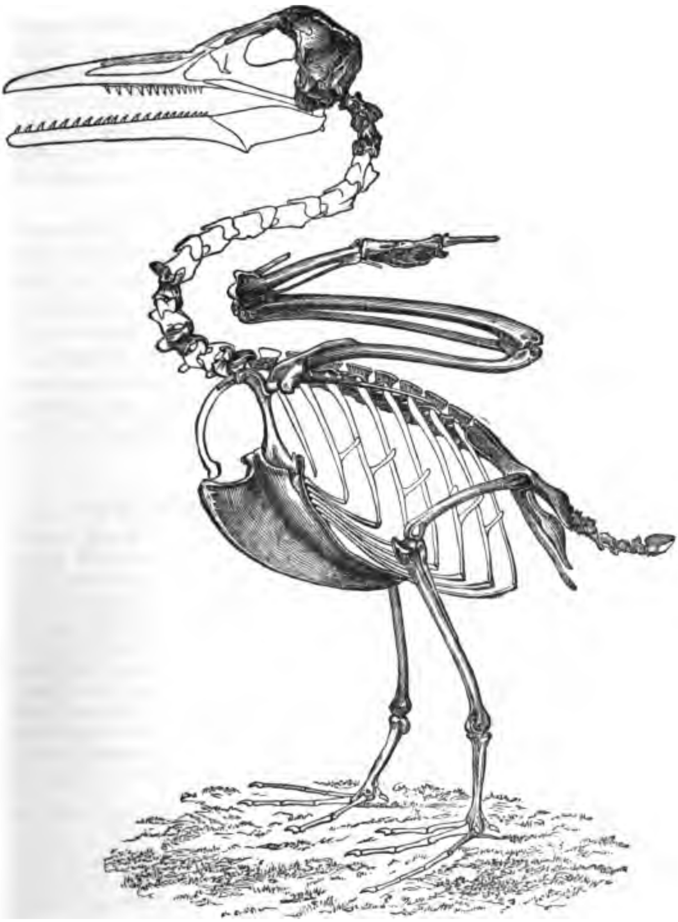
Fig. 264.

Hesperornis regalis, Marsh. Skeleton restored by Professor O. C. Marsh. (About $\frac{1}{10}$ nat. size.) From the Cretaceous of Kansas, N. America.

Among the aquatic Reptiles the existing Chelonians and Crocodiles are represented, but we also find the gigantic snake-like Pythonomorpha (*Mosasaurus*), and survivors of

the remarkable *Ichthyosauria* and *Plesiosauria* which are so abundant in the Jurassic rocks.

Fig. 265.



Ichthyornis victor, Marsh, ½ nat. size. Skeleton restored by Professor O. C. Marsh, who has permitted the use of this and the preceding woodcut. From the Cretaceous of Kansas, N. America.

The terrestrial fauna and flora of the Cretaceous period are much less perfectly known than the marine fauna. The plants

of the Upper Cretaceous appear to be very different, however, from those of the Lower Cretaceous. Among the former we find many of the types of flowering plants so abundant in the Tertiary flora; while the latter, like the Jurassic flora, consist mainly of Conifers, Cycads, and Ferns. Land Reptiles are represented by many genera of Dinosaurs, *Iguanodon* (fig. 316, p. 271), some being of herbivorous and others of carnivorous habit. Pterosaurs, or flying Reptiles, abounded, most of them having toothed jaws, and one form had a spread of wings of over sixteen feet; but with these we have also examples of a form with horny beaks, and a spread of wings of ten feet, in the remarkable *Pteranodon* of Kansas (fig. 263, p. 251).

True Birds of Cretaceous age are known in the *Ichthyornis* (fig. 265) and *Hesperornis* (fig. 264) of Marsh. These birds differ from all existing forms by having teeth implanted in their jaws, and possessing biconcave vertebræ. In the structure of their wings and tails, however, they agree much more closely with living birds than does the *Archæopteryx* of the Jurassic.

Of mammals only small and fragmentary remains have been found in Britain and North America. They appear to have belonged to the same primitive type (Allotheria) as the Jurassic mammals.

British Representatives of the Cretaceous System

The Chalk.—The highest beds of Chalk in England and France consist of a pure white calcareous mass, usually too soft for a building-stone, but sometimes passing into a more solid state. It consists, almost entirely, of calcium carbonate (95–98 per cent.). The stratification is often obscure, except where rendered distinct by interstratified layers of flint, a few inches thick, occasionally in continuous beds, but oftener in nodules, and recurring at intervals generally from two to four feet distant from each other. This Upper Chalk is usually succeeded, in the descending order, by a great mass of Lower or Grey Chalk, without flints, below which comes the Chalk Marl, in which there is a slight admixture of argillaceous matter. The united thickness of the three divisions in the South of England exceeds, in some places, 1,000 feet.

The area over which the Chalk preserves a nearly homogeneous aspect, is so vast, that the earlier geologists despaired of discovering any analogous deposits of recent date. Pure chalk, of nearly uniform aspect and composition, is met with in a north-west and south-east direction, from the North of Ireland to Southern Russia and the Crimea, a distance of about 1,140 geographical miles; and in an opposite direction it extends from the south of Sweden to the south of Bordeaux, a distance of about 840 geographical miles. In Southern Russia, at Kharkov, it is over 1,800 feet thick, and retains the same mineral character as in France and England, with the same fossils, including *Inoceramus Cuvieri*, Sow., *Belemnitella mucronata*, Schlot., and *Ostrea vesicularis*, Lam. (fig. 280, p. 258).

Ordinary white chalk consists of broken and entire Foraminifera, with fragments of *Inoceramus* and other molluscan shells, and the minute Coccoliths and Rhabdoliths already described as occurring in Globigerina-ooze. (See figs. 22–28, p. 50.)

Sometimes chalk can be found which, when carefully washed with water, yields, under the microscope, besides the worn-down material, minute oval or circular-outlined Coccoliths; and often excellent specimens of *Globigerina bulloides*, D'Orb., and other Foraminifera may be obtained. By soaking chalk in Canada balsam and then cutting sections when it has become dry, the Foraminifera and other shells become more frequently visible than might be expected. The commonest genera of the Foraminifera in the Chalk are *Globigerina*, *Rotalia*, *Textularia*, *Nodosaria*, and *Cristellaria*.

The origin of the flints, which form such a conspicuous feature of the Upper White Chalk of England, has given rise to much speculation. There are several facts to be considered before an explanation should be attempted. Silica in the form of nodules of flint or chalcedony is not restricted to the chalk, but may be found in nearly every great series of sedimentary rocks from the latest Tertiary to the Cambrian. The chalk-flints, when in nodular masses, form very definite lines, which are not always those of original deposition. When tabular in form, the flints are often found in joints and fissures which cross the lines of bedding at different angles and reach up to the surface. Some flints (not the tabular masses as a rule) contain relics of organisms, such as Corals, Mollusca, Echinodermata, &c.; while some sponges enter largely into their composition. The original siliceous organisms may remain and be surrounded by chalcedony, or the calcareous shell of a mollusc or cast of an echinoderm may be found in the flint and surrounded by a mass of it. Sometimes not a trace of an organism is to be found in the flint. In the beds between the layers of flints, siliceous replacements of the calcium carbonate of mollusca and echinodermata are common. In some chalks, that of Yorkshire for instance, there has been much replacement of calcium carbonate by silica, a cherty character being produced. Microscopic study of flints shows that they are formed from ordinary chalk by the replacement of the calcium carbonate by silica. The extent to which the colloid silica (opal) has been converted into chalcedony or cryptocrystalline silica, varies greatly in different cases.

The flints and other siliceous bodies are the result of the action of silica in solution upon the calcareous rock, during and after its formation; flints are pseudomorphs, or replacements of calcium carbonate by silica. The source of the silica may be explained by the presence of Radiolaria, Diatomaceæ, and sponges with siliceous skeletons in the deposits. The tabular flints have been formed along planes where solutions of silica have percolated, and the same may sometimes be the case with the nodular flints. There are, as we have already seen, Radiolaria, Diatomaceæ, and siliceous Spongida forming deposits on the floor of the existing ocean.

Potstones. Siliceous sponges of the chalk.—A more difficult problem is presented by the occurrence of certain huge flints, or potstones as they are called in Norfolk, occurring singly, or arranged in nearly continuous columns at right angles to the ordinary and horizontal layers of small flints. The accompanying drawing of a chalk-pit at Horstead, Norfolk, will illustrate the mode of occurrence of these potstones. The potstones, many of them pear-shaped, are usually about three feet in height and one foot in their transverse diameter, placed in vertical rows, like pillars, at irregular distances from each other, but usually from twenty to thirty feet apart, though sometimes nearer together, as in

the sketch (fig. 266). These rows did not terminate downwards in any instance which is seen, nor upwards, except at the point where they were cut off abruptly by the overlying bed of gravel. At the distance of half a mile, the vertical piles of potstones are much farther apart from each other. Dr. Buckland has described very similar phenomena as characterising the Chalk on the north coast of Antrim in Ireland. It has been supposed that these 'Paramoudra' represent gigantic sponges of the Cretaceous period. Whether this be really the case or not, it is certain that the Hexactinellid and Lithistid sponges of the deep sea greatly resemble those of the chalk, and present the peculiar structure which is found in the Ventriculites (fig. 269).

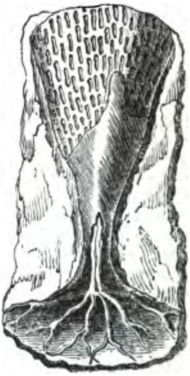
Fig. 266.

From a drawing by Mrs. Gunn.

View of a chalk-pit at Horstead, near Norwich, showing the position of the potstones. (Paramoudra.)

Boulders and groups of pebbles in chalk.—The occurrence here and there in the white chalk of the South of England of isolated pebbles of quartz and green schist has justly excited much wonder. It was at first supposed that they had been dropped from the roots of some floating tree, by which means stones are carried to some of the small coral islands of the Pacific. But the discovery in 1857 of a group of stones in the Chalk at Purley, near Croydon, the largest of which was of granite, and weighed about forty pounds, accompanied by pebbles

Fig. 267.

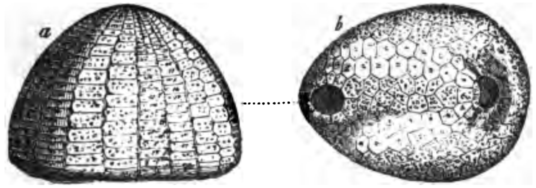


Ventriculites radiatus, Mant. A siliceous and hexactinellid sponge. White Chalk.

and fine sand like that of a beach, has been shown by Mr. Godwin-Austen to be inexplicable except by the agency of floating ice. If we consider that icebergs now reach 40° north latitude in the Atlantic, and several degrees nearer the equator in the southern hemisphere, we can the more easily believe that, even during the Cretaceous epoch, assuming that the climate was milder, fragments of coast-ice may have floated occasionally as far as the south of England.

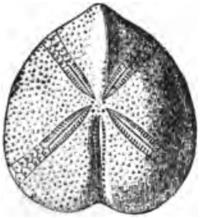
Fossils of the several divisions of the Chalk.—Among the fossils of the Chalk, echinoderms are very numerous; and some of

Fig. 268.



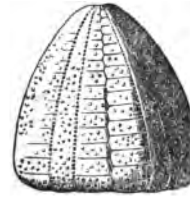
Echinocorys vulgaris, Breyn. (*Ananchytes ovata*, Leske), ½. Chalk, upper and lower.
a. Side view. *b.* Base of the shell on which both the oral and anal apertures are placed; the anal being at the smaller end.

Fig. 269.



Micraster cor-anguinum. Leske, ½. Upper White Chalk.

Fig. 270.

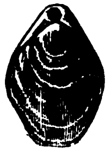


Echinoconus conicus, Breyn. (*Galerites albogalerus*, Lam.), ½. Upper White Chalk.

Fig. 271.

Marsupites Milleri, Mant, ½. Upper White Chalk.

Fig. 272.

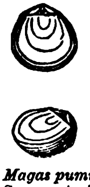


Terebratulina striata. Wahlenb., ½. Upper White Chalk.

Fig. 273.

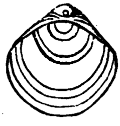
Rhynchonella octoplicata, Sow., ½. (Var. of *R. plicatilis*, Sow.) Upper White Chalk.

Fig 274.



Magas pumila, Sow., nat. size. Upper White Chalk.

Fig. 275.

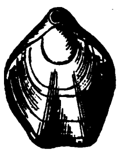


Terebratula carnea, Sow., ½. Upper White Chalk of Norwich.

the genera, like *Echinocorys* (*Ananchytes*, see fig. 268), are exclusively Cretaceous. Among the Crinoidea, the *Marsupites* (fig. 271) is a characteristic genus. Among the mollusca, the Cephalopoda are

represented by *Ammonites*, *Baculites* (fig. 292, p. 261), and *Belemnitella* (fig. 442, p. 327). Although there are eight or more species of *Ammonites* and six of them peculiar to it, this group is much less fully represented than in each of the other subdivisions of the Upper Cretaceous.

Fig. 276.



Terebratula biplicata, Brocchi, ½. Upper Cretaceous.

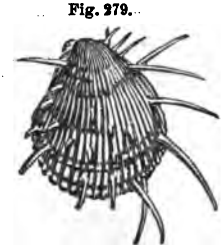
Fig. 277.

Crania parisiensis, Defr., ⅔. Inferior, or attached valve. Upper Chalk.

Fig. 278.

Pecten Beaveri, Sow. ⅓ nat. Lower Chalk, and Chalk marl.

Fig. 279.



Spondylus spinosus, Sow. sp. ½. Upper Chalk.

Among the Brachiopoda in the White Chalk, the *Terebratulæ* are very abundant (see figs. 276, 298). With these are associated some forms of oyster (fig. 280), and other bivalves (figs. 278, 279).

Fig. 280.

Ostrea vesicularis, Lam., ½. Upper Chalk and Upper Greensand.

Fig. 281.

Inoceramus Lamarckii, Park., ⅓. White Chalk.

Among the bivalve mollusca, no form marks the Cretaceous era in Europe, America, and India in a more striking manner than the extinct genus *Inoceramus* (fig. 281), the shells of which are distinguished by a fibrous texture, and are often met with in fragments having probably been extremely friable.

The singular order called *Rudistes* by Lamarck, hereafter to be mentioned as extremely characteristic of the chalk of Southern Europe, has species (figs. 282-285) in the Chalk of England.

Fig. 282.

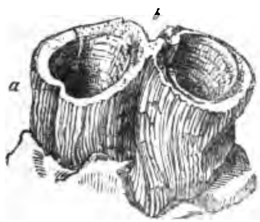


Fig. 283.

Fig. 284.

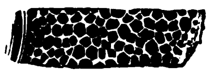


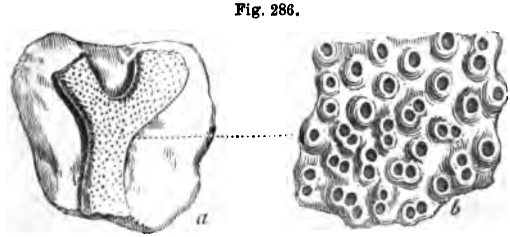
Fig. 285.

Radiolites Mortoni, Mant. Houghton, Sussex. White Chalk.
Diameter one-seventh nat. size.

Fig. 282. Two individuals deprived of their upper valves, adhering together.
283. Same seen from above.
284. Transverse section of part of the wall of the shell, magnified to show the structure.
285. Vertical section of the same.
On the side where the shell is thinnest, there are one external furrow and corresponding internal ridge, *a*, *b*, figs. 282, 283; but they are usually less prominent than in these figures. The upper or opercular valve is wanting.

The general absence of univalve mollusca in the Chalk of England is very marked. Of Bryozoa there is an abundance, such as *Eschara* and *Escharina* (figs. 286, 287). These and other organic bodies, especially sponges, such as *Ventriculites* (fig. 267), are dispersed in-

Fig. 286.

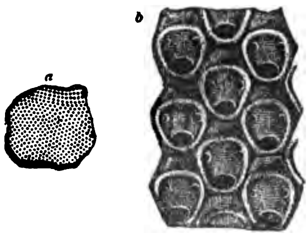


Eschara disticha, Goldf. White Chalk.
a. Natural size. *b*. Portion magnified.

differently through the soft chalk and hard flint, and some of the flinty nodules owe their irregular forms to enclosed sponges, such as fig. 288 *a*, where the hollows in the exterior are caused by the branches of a sponge (fig. 288, *b*), seen on breaking open the flint.

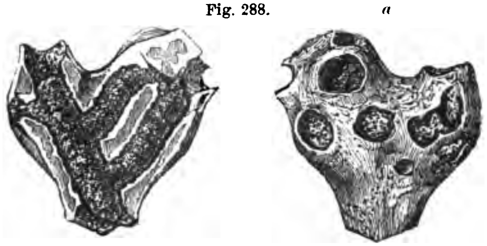
The remains of fishes of the Upper Cretaceous formations consist chiefly of teeth belonging to the shark family, of the genera *Lamna* and *Otodus*, for instance. Some of the genera are common to the Tertiary formations, but many are distinct. To the latter belongs

Fig. 287.



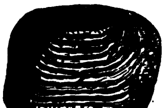
Escharina oceani, D'Orb.
a. Natural size.
b. Part of the same magnified.
White Chalk.

Fig. 288.



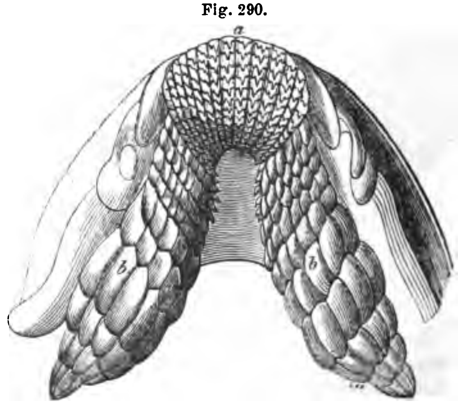
A branching sponge in a flint, from the White Chalk.
From the collection of Mr. Bowerbank.

Fig. 289.



Palatal tooth of *Ptychodus decurrens*, $\frac{2}{3}$.
Lower White Chalk.
Maidstone.

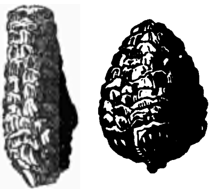
Fig. 290.



Cestraceon Phillippi, Cuv.; recent.
Port Jackson. Buckland. Bridgwater Treatise, Pl. 27, *d*.

the genus *Ptychodus* (fig. 289), which is allied to the living Port-Jackson shark, *Cestraceon Phillippi*, Cuv., the anterior teeth of which (see fig. 290, *a*) are sharp and cutting, while the posterior or palatal teeth (*b*) are flat. The Teleostean division, to which most of the living bony fishes belong, appears to have been fairly represented in Cretaceous times, and it is represented by species of *Beryx*, a genus still existing in the Atlantic and Pacific Oceans. But we meet with no bones of land animals, nor any terrestrial or fluviatile shells, nor any plants, except seaweeds, and here and there a piece of drift-wood. All the appearances concur in leading us to conclude that the Chalk was the product of an open sea of great depth.

Fig. 291.



Coprolites of fish, from the Chalk.

The collector of fossils from the Chalk was formerly puzzled by meeting with certain bodies which were called 'larch-cones,' which were afterwards recognised by Dr. Buckland to be the excrement of fish (fig. 291). They are composed in great part of phosphate of lime.

Certain bands in the Chalk are found largely converted into calcium phosphate, and constitute a valuable manure. Of these phosphatic chalks we have an example in this country at Taplow.

The Middle and Lower Chalk have yielded twenty-five species of *Ammonites*, of which one half are peculiar to these divisions. The genera *Baculites*, *Hamites*, *Scaphites*, *Turrilites*, *Nautilus*, and *Belemnitella*, are also represented. At the top of the Middle Chalk is found the hard cream-coloured Chalk-rock. Below this is a thickness of at least 220 feet of Chalk, with some few flint bands near the top. This part is full of fragments of shells, and may be divided into three zones—the zone of *Holaster planus*, Mant., at the top, that of *Terebratulina gracilis*, Schloth., next below, and at the bottom the zone

Fig. 292.

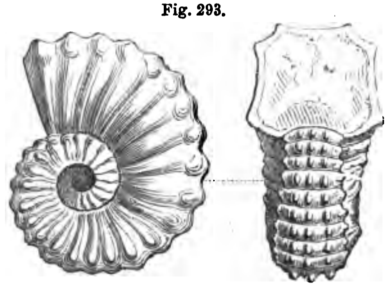
Baculites anceps, Lam., ½. Lower Chalk.

of *Inoceramus labiatus*, Schloth. These zones rest upon the gritty and nodular chalk known as the Melbourn Rock, which forms the base of the series. It contains the *Inoceramus* just noticed, with *Echinoconus subrotundus*, Mant., &c. The Middle Chalk is the equivalent of the continental Turonian, and there is a considerable palæontological break between it and the underlying Cenomanian or Lower Chalk with Chalk-marl.

The fairly well defined bed of yellowish gritty chalk, referred to under the name of 'Melbourn Rock,' may be seen, in some places in the south-east of England, in cliff sections lying below the Chalk without flints. It contains *Actinocamax* (*Belemnitella*) *plenus*, Blain. sp., and *Radiolites Mortoni*, Mant. It merges downwards into the Grey Chalk, which is somewhat grey in colour and destitute of flints. The Lower Chalk contains several zones of fossils, of which that

just mentioned may be considered the top. Beneath the zone with *Actinocamax* (*Belemnitella*) *plenus*, Blain. sp., is that of *Holaster subglobosus*, Ag., and *Discoidea cylindrica*, Ag. A lower zone contains *Ammonites* (*Acanthoceras*) *rothomagensis*, Defr., *A.* (*Schloenbachia*) *varians*, J. Sow., and *Pecten Beaveri*, Sow.

Fig. 293.



Ammonites (*Acanthoceras*) *rothomagensis*, Defr., ½. Chalk-marl. Back and side view.

In the neighbourhood of Dunstable, the hard Totternhoe stone lies at the base of the Grey Chalk, and both overlie the true Chalk-marl.

Chalk-marl.—This is an argillaceous chalk, and it forms with the next division the base of the true Chalk formation. It is seen

Fig. 294.

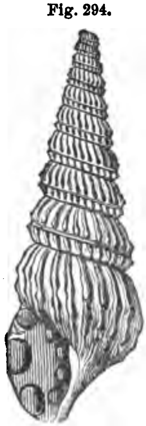


Fig. 295.

Scaphites æqualis, Sow., ½. Chloritic marl and sand, Dorsetshire.

a

Turrilites costatus, Lam., ½. Lower Chalk and Chalk-marl.
a. Section, showing the foliated border of the sutures of the chambers.

at Folkestone and in the Isle of Wight, and contains amongst the common fossils *Scaphites æqualis*, Sow. (fig. 295), *Turrilites costatus*, Lam. (fig. 294), *Ammonites* (*Acanthoceras*) *Mantelli*, Sow., and *Lima globosa*, Sow.

Chloritic Marl.—This yellow or whitish chalky marl contains grains of glauconite, and phosphatic nodules. It yields *Ammonites* (*Acanthoceras*) *Mantelli*, Sow., *A.* (*Schloenbachia*) *varians*, J. Sow., *A.* (*Acanthoceras*) *laticlavius*, Sharpe, *Nautilus lævigatus*, D'Orb., *Terebratula biplicata*, Sow., &c.

The *Greensand of Cambridge*, a bed about a foot thick, lying at the base of the chalk of Cambridge, is a glauconitic marl with phosphatic nodules, rolled fossils, and erratic blocks. It is the equivalent of the Chloritic marl, forms the base of the Chalk-marl, and rests unconformably on the Gault, from the denudation of which its rolled fossils have been derived. Numerous reptilian and other bones have

Fig. 296.

Ostrea columba. Lam ½. Upper Greensand.

Fig. 297.

Ostrea carinata, Lam., ½. Chalk marl and chloritic sand.

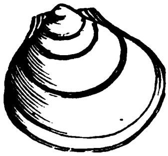
Fig. 298.

Terebrirostra lyra, Sow., ½. Upper Greensand and marl.

Fig. 299.

Pecten (*Janira*) *quinquecostatus*, Sow., ½. Lower Chalk and Chalk-marl.

Fig. 300.



Lima (*Plagiostoma*) *Hoperi*, Sow. ½. Syn. *Lima Hoperi.* White Chalk.

been found in this deposit belonging to Chelonians, Lacertilia, Crocodiles (*Polyptychodon*), Dinosauria, Mosasauria, many species of *Pterodactylus*, small and large, and species of *Plesiosaurus* and *Ichthyosaurus*. Two species of true birds occur (belonging to the genus *Enaliornis*), and Professor H. G. Seeley considers them to have been swimming birds.

The Red Chalk of Hunstanton is probably of about the same geological age as the Cambridge Greensand, its colour being due to oxidation of the glauconite.

Upper Greensand.—The sandy strata of this age, often greenish in colour, are not very readily separable from the Chalk-marl. The formation may be divided into an upper zone with *Pecten asper*, Lam.,

and a lower with *Ammonites* (*Schloenbachia*) *rostratus*, J. Sow. But there is a mixture of Chalk-marl, Chloritic-marl, and even of Gault species in this series, so that it is very debateable ground. It is well developed in Devon and Somerset. The Warminster beds contain *Micrabacia coronula*, Edw. and H., *Ostrea carinata*, Lam. (fig. 297), *Pecten asper*, Lam., *Terebratula biplicata*, Sow., and the Blackdown beds have *Trigonia alæformis*, Park., *Pecten* (*Janira*) *quinquecostatus*, Sow. (fig. 299), and *Exogyra conica*, Lam.

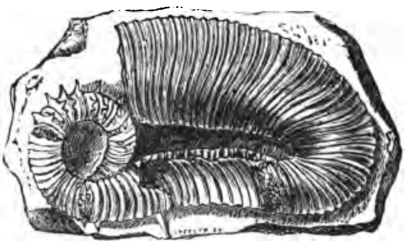
The development of this series is slight in the Kentish area, but it is well seen in the Isle of Wight and again in Antrim.

Among the characteristic mollusca of the Upper Greensand may be mentioned *Terebrirostra lyra*, Sow. (fig. 298), *Pecten quinquecostatus*, Sow. (fig. 299), and *Ostrea columba*, Lam. (fig. 296).

The Cephalopoda are abundant: 40 species of *Ammonites* are now known, 10 being peculiar to this subdivision, and the rest common to the beds immediately above or below.

Gault.—The lowest member of the Upper Cretaceous group, usually about 100 feet thick in the S.E. of England, is provincially termed Gault. It is a stiff dark-blue marl, sometimes intermixed

Fig. 301.



Ancyloceras spinigerum, D'Orb. Syn. *Hamites spiniger*, Sow.
Near Folkestone. Gault.

with greensand. Messrs. De Rance and Price have shown that one of the best sections is at Copt Point, near Folkestone, where the upper and lower divisions of the series can be seen. The upper division contains *Ammonites* (*Schloenbachia*) *rostratus*, Sow., *Kingena lima*, Defr., *Scaphites æqualis*, Sow., *Ammonites* (*Schloenbachia*) *cristatus*, De Luc., and nearly half of its species pass up into the superincumbent beds. The lower division rests on Lower Cretaceous rocks, overlaps them, and lies in turn on the various beds of the Jurassic system, showing the physical break between the Lower and Upper Cretaceous formations. About one-eighth only of the fossils pass from the Lower into the Upper Gault. The lower division contains *Ammonites* (*Hoplites*) *auritus*, Sow., *A.* (*Hoplites*) *lautus*, Sow., *Solarium moniliferum*, Mich., *Ancyloceras spinigerum*, D'Orb. (fig. 301), numerous corals and crabs, and species of *Crioceras* and *Hamites*.

The great break between the Upper and Lower Cretaceous is shown by the remarkable unconformity and overlap (overstep) of the chalk on all the other strata. (See fig. 109, p. 101).

The researches of M. Barrois, Mr. Price, and other authors have shown that the English Upper Cretaceous consists of a number of sub-

divisions or zones, each characterised by a peculiar assemblage of fossils. These zones are as follows :—

Senonian (Upper Chalk)	Zone of *Belemnitella mucronata*, Schloth.	
	" " *Belemnitella quadrata*, Defr.	
	" " *Marsupites*	
	" " *Micraster cor-anguinum*, Forbes	
	" " *Micraster cor-testudinarium*, Goldf.	
	" " *Holaster planus*, Mant. (Chalk Rock)	
Turonian (Middle Chalk)	Zone of *Terebratulina gracilis*, Schloth.	
	" " *Inoceramus labiatus*, Schloth., and *Rhynchonella Cuvieri*, Sow.	
Cenomanian (Lower Chalk and U. Greensand)	Zone of *Belemnitella* (*Actinocamax*) *plena*, Blain. (Melbourn Rock)	
	" " *Ammonites* (*Acanthoceras*) *rothomagensis*, Defr.	
	" " *Holaster subglobosus*, Ag.	
	" " *Ammonites* (*Schloenbachia*) *varians*, Sow., and *Rhynchonella Martini*, Mant.	
	" " *Plocoscyphia meandrina*, Röm. sp.	
	" " *Pecten asper*, Lam.	
Albian (Gault)	Zone of *Ammonites* (*Schloenbachia*) *inflatus*, Sow.	Upper Gault
	" " *Kingena lima*, Defr.	Upper Gault
	" " *Ammonites* (*Schloenbachia*) *varicosus*, Sow.	Upper Gault
	" " *Ammonites* (*Schloenbachia*) *cristatus*, De Luc.	Junction bed
	" " *Ammonites* (*Hoplites*) *auritus*, Sow.	Junction bed
	" " *Ammonites* (*Hoplites*) *denarius*, Sow.	Lower Gault
	" " *Ammonites* (*Hoplites*) *lautus*, Sow.	Lower Gault
	" " *Ammonites* (*Schloenbachia*) *Delaruei*, D'Orb.	Lower Gault
	" " *Crustacea*	Lower Gault
	" " *Ammonites* (*Hoplites*) *auritus*, Sow. var.	Lower Gault
	" " *Ammonites* (*Hoplites*) *interruptus*, Brug.	Lower Gault

UPPER NEOCOMIAN ('LOWER GREENSAND')

The sands which crop out beneath the Gault in Wiltshire, Surrey, and Sussex are sometimes in the uppermost part pure white, at other times of a yellow, green, or brown colour, and some of the beds con-

tain much ferruginous matter. At Hythe they contain layers of calcareous rock and chert, and at Maidstone and other parts of Kent the limestone called Kentish Rag is intercalated. This somewhat sandy and calcareous rock forms strata two feet thick, alternating with quartzose sand. The total thickness of these sandstone and calcareous beds is less than 300 feet, and the Hythe beds are seen to rest immediately on a grey clay, to which we shall presently allude as the Atherfield clay. Among the fossils of the Hythe beds we may mention *Nautilus plicatus*, Sow. (fig. 302), *Ancyloceras* (*Scaphites*) *gigas*, D'Orb. (fig. 303)—which has been aptly described as an Ammonite more or less uncoiled—*Trigonia caudata*, Ag. (fig. 305), *Gervillia anceps*, Desh. (fig. 304)—a bivalve genus allied to Avicula—and *Terebratula sella*, Sow. (fig. 306). In ferruginous beds of the same age in Wilt-

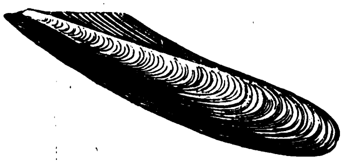
Fig. 302.

Nautilus plicatus, Sow., ½, in Fitton's Monog.

Fig. 303.

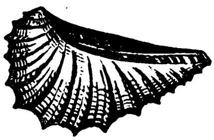
Ancyloceras gigas, D'Orb, ½.

Fig. 304.



Gervillia anceps, Desh., ½. Upper Neocomian, Surrey.

Fig. 305.



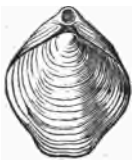
Trigonia caudata, Ag., ½. Upper Neocomian.

shire is found the remarkable shell called *Diceras Lonsdalii*, Sow. (fig. 307), belonging to the Chamidæ, which abounds in the Upper and Middle Neocomian of Southern Europe.

M. Barrois and other authors regard the Folkestone beds or 'Car stone,' which form the upper member of the Lower Greensand, as being closely connected with the Gault, and they believe that an

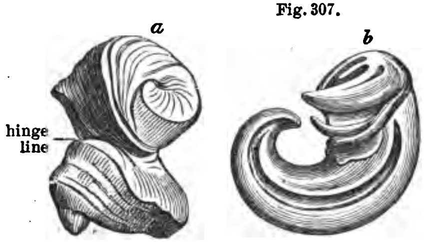
unconformity accompanied by a great change in fossils exists between the Folkestone beds and the underlying members of the 'Lower Greensand.' If this view be correct, the Folkestone beds will have to

Fig. 306.



Terebratula sella, Sow., ½. Upper Neocomian, Hythe.

Fig. 307.

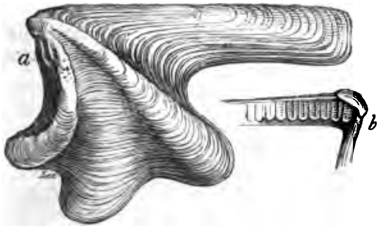


Diceras Lonsdalii, Sow., ½. Upper Neocomian, Wilts
a. The bivalve shell.
b. Cast of one of the valves enlarged.

be removed from the Neocomian and grouped with the Upper Cretaceous.

Atherfield clay.—We mentioned before that the Hythe series rests on a grey clay. This clay is only of slight thickness in Kent and Surrey, but is better developed at Atherfield, in the Isle of Wight. The difference, indeed, in mineral character and thickness of the Upper Neocomian formation near Folkestone, and the corresponding beds in the south of the Isle of Wight, about 100 miles distant, is truly remarkable. In the latter place we find no limestone answering to the Kentish Rag, and the entire thickness from the bottom of the Atherfield clay to the top of the Neocomian, instead of

Fig. 308.



Perna Mulleti, Desh., ½ nat. size.

a. Exterior.
b. Part of hinge-line of upper or right valve.

being less than 300 feet as in Kent, is given by the late Professor E. Forbes as 843 feet, which he divides into sixty-three strata, forming three groups. The uppermost of these consists of ferruginous sands; the second of sands and clay, and the third or lowest of a brown clay abounding in fossils.

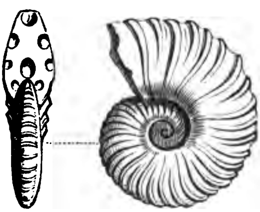
Pebbles of quartzose sandstone, jasper, and flinty slate, together with grains of chlorite and mica, occur in the Lower Greensand of Surrey; and fragments and water-worn fossils of the Jurassic rocks speak plainly, as Mr. Godwin-Austen has shown, of the nature of the pre-existing formations, by the wearing down of which the Neocomian beds were formed. The land consisting of such rocks

was doubtless submerged before the origin of the Chalk, a deposit which was formed in a more open and probably deeper sea, and in clearer waters.

Among the shells of the Atherfield clay the most characteristic, perhaps, is the large *Perna Mulleti*, Sow., of which a reduced figure is here given (fig. 308).

Speeton clay.—On the coast beneath the Chalk of Flamborough Head, in Yorkshire, an argillaceous formation crops out, called the Speeton clay. It is several hundred feet in thickness, and its palæontological relations have been worked out by Professor Judd, and later by Mr. Lamplugh, and it has been shown that it is separable into three divisions, the uppermost of which, 150 feet thick, and containing 87 species of mollusca, decidedly belongs to the Atherfield clay and associated strata of Hythe and Folkestone, already described. It is characterised by the *Perna Mulleti* Desh. (fig. 308), and *Terebratula sella*, Sow. (fig. 306), and by *Ammonites* (*Hoplites*) *Deshayesii*, Leym. (fig. 309), a well-known Hythe and Atherfield fossil. Remains of skeletons of the genera *Plesiosaurus* and *Teleosaurus* have been obtained from this clay. At the base of this upper division of the Speeton clay there occurs a layer of large Septaria, formerly worked for the manufacture of cement. This bed is crowded with fossils, especially *Ammonites*, some of which are of great size.

Fig. 309.



Ammonites (*Hoplites*) *Deshayesii*, Leym., $\frac{1}{2}$. Upper Neocomian.

MIDDLE NEOCOMIAN

Tealby series.—At Tealby, a village in the Lincolnshire Wolds, there occur, beneath the White Chalk, some non-fossiliferous

Fig. 310.

Pecten cinctus, Sow. (*P. crassitesta*, Röm.) Middle Neocomian, England; Middle and Lower Neocomian, Germany. $\frac{1}{8}$ nat. size.

Fig. 311.

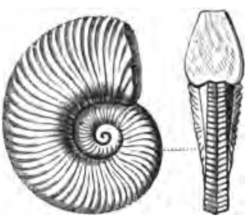
Ancyloceras (*Crioceras*) *Duvallii*, Leveillé. Middle and Lower Neocomian. $\frac{1}{4}$ nat. size.

ferruginous sands about twenty feet thick, beneath which are beds of clay and limestone about fifty feet thick, with an interesting suite of fossils, among which are *Pecten cinctus*, Sow. (fig. 310), from 9 to 12 inches in diameter, *Ancyloceras Duvallii*, Leveillé (fig. 311), and some 40 other shells, many of them common to the Middle Speeton clay, about to be mentioned. As *Ammonites* (*Placenticeras*) *clypeiformis*, D'Orb., and *Terebratula hippopus*, Röm., found in these beds, characterise the Middle Neocomian of the Continent, it is to this stage that the Tealby series must be assigned.

The middle division of the Speeton clay, occurring at Speeton below the cement-bed, before alluded to, is 150 feet thick and contains about 39 species of mollusca, half of which are common to the overlying clay. Among the shells are *Ancyloceras Duvallii*, Leveillé (fig. 311) and *Pecten cinctus*, Sow. (fig. 310).

Lower Neocomian.—In the lower division of the Speeton clay, 200 feet thick, 46 species of mollusca have been found, and three divisions, each characterised by its peculiar ammonite, have been noticed. The central zone is marked by *Ammonites* (*Hoplites*) *noricus*, Schloth. (see fig. 312). On the Continent these beds are well known by their corresponding fossils, the Hils-thon and conglomerate of the North of Germany agreeing with the Middle and Lower Speeton; the latter of which, with the same mineral characters and fossils as in Yorkshire, is also found in the little island of Heligoland.

Fig. 312.



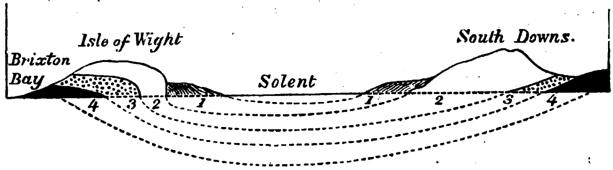
Ammonites (*Hoplites*) *noricus*, Schloth., nat. size. Lower Neocomian. Speeton.

Wealden Formation.—Beneath the Atherfield clay or Upper Neocomian of the S.E. of England, a freshwater or delta formation is found, called the Wealden, which, although it occupies a small horizontal area in Europe, as compared with the Chalk and the marine Neocomian beds, is nevertheless of great geological interest, since the embedded remains give us some insight into the nature of the terrestrial fauna and flora of the Lower Cretaceous epoch. The name of Wealden was given to this group because it was first studied in parts of Kent, Surrey, and Sussex, called the Weald; and we are indebted to Dr. Mantell for having shown, in 1822, in his 'Geology of Sussex,' that the whole group was of fluviatile origin. In proof of this he called attention to the entire absence of Ammonites, Belemnites, Brachiopoda, Echinodermata, Corals, and other marine fossils, so characteristic of the Cretaceous rocks above, and of the Oolitic strata below, and to the presence of Paludinæ, Melaniæ, Cyrenæ, and various fluviatile shells, as well as the bones of terrestrial reptiles and the trunks and leaves of land-plants.

The evidence of so unexpected a fact as that of a dense mass of purely freshwater origin underlying a deep-sea deposit (a phenomenon with which we have since become familiar) was received, at first, with no small doubt and incredulity. But the relative position of the beds is unequivocal; the Weald clay being distinctly seen to pass beneath the Atherfield clay in various parts of Surrey, Kent, and

Sussex, and to reappear in the Isle of Wight at the base of the Cretaceous series, being, no doubt, continuous far beneath the surface, as indicated by the dotted lines in the annexed diagram (fig. 313).

W.S.W. Fig. 313. E.N.E.



1. Tertiary. 2. Chalk and Gault. 3. Upper Neocomian (or Lower Greensand). 4. Wealden (Weald Clay and Hastings Sand).

They are also found occupying the same relative position below the chalk in the peninsula of Purbeck, where, as we shall see in the sequel, they rest on strata referable to the Upper Oolite.

Weald Clay.—The upper division, or Weald clay, 1,000 feet thick, is, in great part, of freshwater origin, but in its highest portion contains beds of oysters and other marine shells which indicate fluvio-marine conditions. The uppermost beds are not only conformable to the inferior strata of the overlying Neocomian, but are of similar mineral composition. To explain this, we may suppose

Fig. 314. Fig. 315.

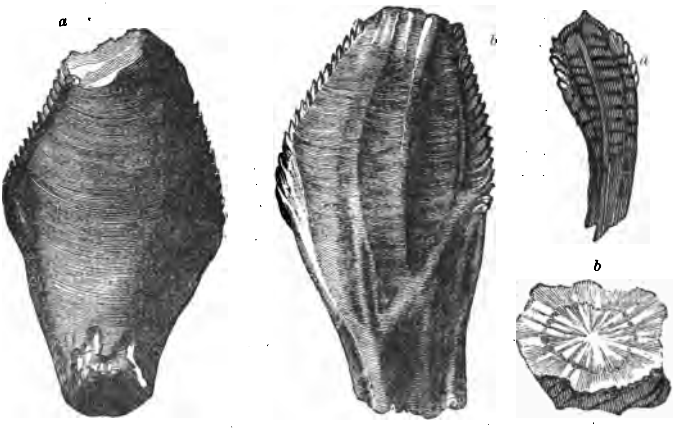
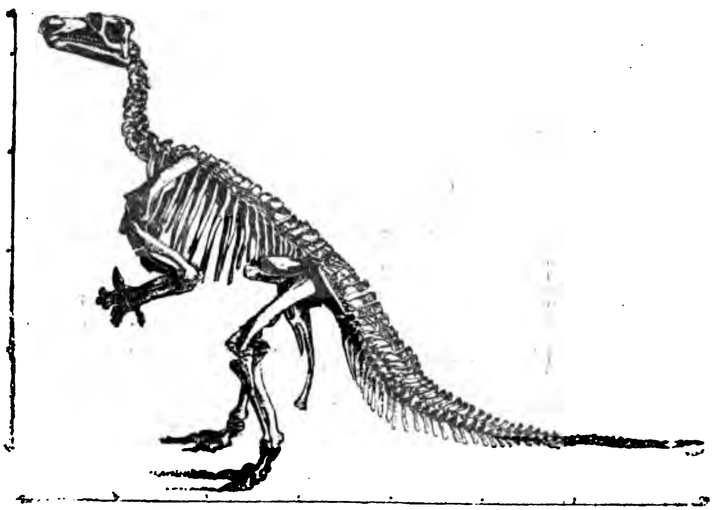


Fig. 314. *a. b*, Tooth of *Iguanodon Mantelli*, Meyer, nat. size.
Fig. 315. *a.* Partially worn tooth of young individual of the same.
b. Crown of tooth in adult, worn down. (Mantell.)

that, as the delta of a great river was tranquilly subsiding, so as to allow the sea to encroach upon the space previously occupied by fresh water, the river still continued to carry down the same sediment into the sea. In confirmation of this view it may be stated, that

the remains of the *Iguanodon Mantelli*, Meyer, and also species of the genera *Hypsilophodon*, *Pelorosaurus*, *Ornithopsis*, and *Hylæosaurus*, gigantic terrestrial reptiles, belonging to the order Dinosauria, have been discovered near Maidstone, in the overlying Kentish Rag, or marine limestone of the Upper Neocomian, and in the Isle of Wight and elsewhere. Hence we may infer that some of the Reptilia which inhabited the country of the great river which formed the Wealden delta, continued to live when part of the district had become submerged beneath the sea. Thus, in our own times, we may suppose the bones of large crocodiles to be frequently entombed in recent freshwater strata in the delta of the Ganges. But if part of that delta should sink down so as to be covered by the sea, marine formations might

Fig. 316.



Iguanodon Bernissartensis, Boulenger. Almost complete skeleton. About $\frac{1}{75}$ nat. size. From the Wealden of Belgium.

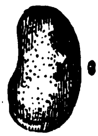
begin to accumulate in the area in which freshwater beds had previously been formed; and yet the Ganges might still pour down its turbid waters in the same direction, and carry seaward the carcases of the same species of crocodile; and in this case their bones might be included in marine as well as in subjacent freshwater strata.

Complete skeletons of *Iguanodon* have been found in Belgium, one of which showing the general structure of these remarkable extinct reptiles is shown in fig. 316.

Occasionally bands of limestones called Sussex Marble occur in the Weald clay, almost entirely composed of a species of *Paludina*, closely resembling the common *P. vivipara*, L., of English rivers.

Shells of the *Cypridea* (fig. 317), a genus of Ostracoda before mentioned as abounding in lakes and ponds, are also plentifully scattered through the clays of the Wealden, sometimes producing, like plates of mica, a thin lamination (see fig. 318).

Fig. 317.



Cypridea spinigera, Fitton.

Fig. 318.

Weald Clay, with Cypridæ.

Hastings Sands.—This lower division of the Wealden consists of sand, sandstone, calciferous grit, clay, and shale; the argillaceous strata, notwithstanding the name, predominating somewhat over the arenaceous, as will be seen by reference to the following section, drawn up by Messrs. Drew and Foster, of the Geological Survey of Great Britain:—

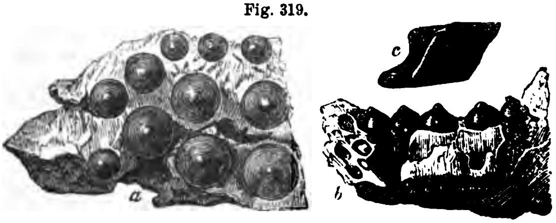
	Names of Subordinate Formations.	Mineral Composition of the Strata.	Thickness in Feet.
Hastings Sand	Tunbridge Wells Sand . .	Sandstone and loam . .	150
	Wadhurst Clay .	Blue and brown shale and clay with a little calc-grit	100
	Ashdown Sand .	Hard sand with some beds of calc-grit . . .	160
	Ashburnham Beds	Mottled, white and red clay with some sandstone .	330

The picturesque scenery of the 'High Rocks' and other places in the neighbourhood of Tunbridge Wells is caused by the steep natural cliffs, to which a hard bed of white sand, occurring in the upper part of the Tunbridge Wells Sand, mentioned in the above table, gives rise. This bed of 'rock-sand' varies in thickness from 25 to 48 feet. Large masses of it, which were by no means hard or capable of making a good building-stone, form, nevertheless, projecting rocks with perpendicular faces, and resist the degrading action of the river because, says Mr. Drew, they present a solid mass without planes of division. The calcareous sandstone and grit of Tilgate Forest, near Cuckfield, in which the remains of the *Iguanodon* and *Hylæosaurus* were first found by Dr. Mantell, constitute an upper member of the Tunbridge Wells Sand, while the 'sand-rock' of the Hastings cliffs, about 100 feet thick, is one of the lower members of the same. The reptiles, which are very abundant in this division, consist partly of marine saurians, among which we find the *Megalosaurus* and *Plesiosaurus*. The *Pterodactylus* is also met with in the same strata, and many remains of Chelonians of the genera *Trionyx* and *Emys*, now confined to tropical regions.

The fishes of the Wealden are chiefly referable to the Ganoid and Placoid orders. Among them the teeth and scales of *Lepidotus*

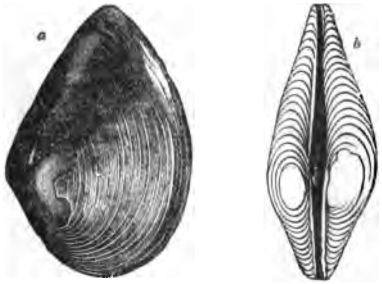
are most widely diffused (see fig. 319). These ganoids were allied to the *Lepidosteus*, or Gar-pike, of the American rivers. The whole body was covered with large and very thick rhomboidal scales,

Fig. 319.



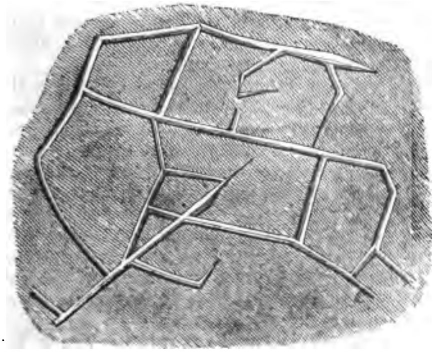
Lepidotus Mantelli, Ag. Wealden.
a. Palate and teeth. *b.* Side view of teeth. *c.* Scale.

Fig. 320.



Unio valdensis, Mant., $\frac{1}{2}$.
Isle of Wight and Dorsetshire; in the lower beds of the Hastings Sands.

Fig. 321.



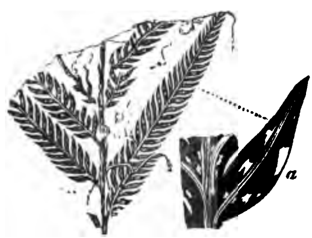
Underside of slab of sandstone about one yard in diameter, showing casts of 'sun-cracks.' Stammerham, Sussex.

having the exposed part coated with enamel. Most of the species of this genus are supposed to have been either river-fish, or inhabitants of the sea at the mouth of estuaries.

At different horizons in the Hastings Sand we find again and again slabs of sandstone with strong ripple marks, and between these slabs are beds of clay many yards thick. In some places, as at Stammerham, near Horsham, there are indications of this clay having been exposed so as to dry and crack before the next layer was thrown down upon it. The open cracks in the clay have served as moulds, of which casts have been taken in relief, and which are, therefore, seen on the lower surface of the sandstone (see fig. 321).

Near the same place a reddish sandstone occurs in which are innumerable remains of a fern, apparently a *Sphenopteris*, the stems and fronds of which are disposed as if the plants were standing erect on the spot where they originally grew, the sand having been gently deposited upon and around them; and similar appearances have been remarked in other places in this formation. In the same division also of the Wealden, at Cuckfield, is a bed of gravel or conglomerate, consisting of water-worn pebbles of quartz and jasper, with rolled bones of reptiles. These must have been drifted by a current, probably in water of no great depth.

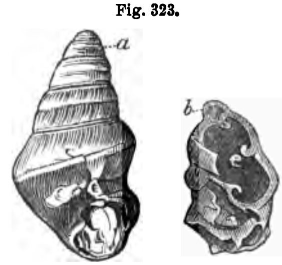
Fig. 322.



Sphenopteris gracilis, Fitton. From the Hastings Sands near Tunbridge Wells.

a. Portion of the same magnified.

Fig. 323.



Vicarya Lujani, De Verneuil. Wealden, Punfield.

a. Nearly perfect shell. *b.* Vertical section of smaller specimen, showing continuous ridges, as in *Nerinæa*.

From such facts we may infer that, notwithstanding the great thickness of this division of the Wealden, the whole of it was a delta deposit, in water of a moderate depth, and often extremely shallow. This idea may seem startling at first, yet such would be the natural consequence of a gradual and continuous sinking of the sea-bottom in an estuary or bay, into which a great river discharged its turbid waters. By each foot of subsidence, the fundamental rock would be depressed one foot farther from the surface; but the bay would not be deepened, if newly deposited mud and sand should raise the bottom one foot. On the contrary, such new strata of sand and mud might be frequently laid dry at low water, or overgrown for a season by a vegetation proper to marshes.

Punfield beds, brackish and marine.—These beds are higher than the Wealden proper. The shells of the Wealden beds belong to the genera *Melanopsis*, *Melania*, *Paludina*, *Cyrena*, *Cyclas*, *Unio* (see fig. 320), and others, which inhabit estuaries, rivers or lakes; but one bed has been found at Punfield, in Dorset-

shire, where the genera *Corbula*, *Mytilus*, and *Ostrea* occur, indicating a brackish state of the water; and in some places this bed becomes purely marine, containing some well-known Neocomian fossils, among which *Ammonites* (*Hoplites*) *Deshayesii*, Leym (fig. 309) may be mentioned. Others are peculiar as British fossils, but very characteristic of the Upper and Middle Neocomian of the North of Spain, and among these the *Vicarya Lujani*, De Verneuil (fig. 323), a shell allied to *Nerinæa*, is conspicuous. The middle Neocomian beds of Spain, in which this shell abounds, attain at Utrillas a thickness of 530 feet, and contain ten beds of coal, lignite, or jet, which are extensively worked.

The classification of the Cretaceous strata into zones distinguished by groups of characteristic fossils has been brought about by the labours of the French geologists D'Orbigny, Hébert, and Barrois. The last-mentioned author has shown how this classification may be applied to English strata in his 'Recherches sur le Terrain Crétacé Supérieur de l'Angleterre et de l'Irlande' (1876). Valuable information on the Cretaceous strata of the Wealden area and the Isle of Wight will be found in the Memoirs of the Geological Survey on those districts. Mr. Jukes-Browne is engaged upon the preparation of a memoir on the Cretaceous deposits of England. Dr. W. F. Hume has given an admirable sketch of the Upper Cretaceous rocks in his memoir published in the 'Proc. Geol. Assoc.,' 1894. A full account of the Speeton Clay, with figures of its fossils, with notes on its relation to strata in Russia, has been recently published by Lamplugh and Pavlov.

CHAPTER XVII

THE JURASSIC SYSTEM

Classification of Jurassic strata—Foraminifera, Sponges, Corals, Echinodermata, Brachiopoda, Lamellibranchiata, Gastropoda, and Cephalopoda of Jurassic rocks—Fishes, reptiles, birds, and mammals of the Jurassic rocks—Terrestrial Flora of the Jurassic period—Purbeck strata—Purbeck mammals—Dirt beds—Portlandian—Kimeridge Clay Coralline Oolite—Oxford Clay—Cornbrash—Forest Marble—Great Oolite—Stonesfield Slate with its Mammalia—Inferior Oolite—Upper Lias sand and clay—Marlstone and Middle Lias—White Lias and Rhætic beds.

Nomenclature and classification of the Jurassic strata. The name of this great system of stratified rocks is derived from the Jura Mountains, where the formations are admirably developed, and were carefully studied by Marcou. In England, and also in France, the system is usually divided into two members, the upper of which is called 'Oolite,' from the prevalence in it of limestones of oolitic structure, and the lower 'Lias,' a provincial term applied to the finely laminated beds of clay and limestone of which it is chiefly made up. In Germany the system is usually divided into three members, which bear the names of White Jura or Malm, Brown Jura or Dogger, and

Black Jura or Lias. The German Dogger is the equivalent of the Lower Oolite of England.

It was while studying the Jurassic rocks that William Smith was first able to establish the important principle that strata can be identified by their organic remains; and the chief subdivisions of the Oolitic and Liassic rocks still bear the names (often of provincial origin) first applied to them by Smith. The general order of succession and approximate thicknesses of the beds of this system, as seen in the south-west of England, are given in the following table:—

OOLITIC STRATA.	Upper or Portland Oolites.	Purbeck beds, 300 feet.
		Portland Oolite and sand, 200 feet.
		Kimeridge clay, 600 feet.
	Middle or Oxford Oolites.	Coral-rag and calcareous grit (coralline Oolite or Corallian), 250 feet.
		Oxford clay, with Kellaways rock, 600 feet (Callovian).
	Lower or Bath Oolites.	Cornbrash, 25 feet.
		Forest marble with Bradford clay, 150 feet.
		Great Oolite with Stonesfield slate, 120 feet.
		Fuller's earth, 150 feet.
		Inferior Oolite (including ragstones, freestones, the oolite-marl, pea-grit, and sands), 270 feet.
LIASSIC STRATA.	Upper Lias.	Midford sand, 200 feet.
		Upper Lias clays, 200 feet.
	Middle Lias.	Marlstone rock-bed, 400 feet.
		Middle Lias clays, 400 feet.
	Lower Lias.	Lower Lias clays, 800 feet.
		Lower Lias limestone and shale, 800 feet.

White Lias and Rhætic or Avicula-contorta beds.

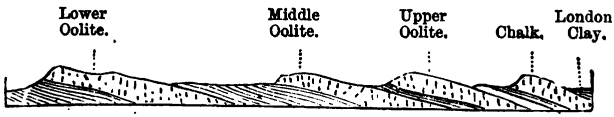
It should be noted that the terms *Great* Oolite and *Inferior* Oolite are used in the sense of *principal* Oolitic limestone and *lower* Oolitic limestone.

As in the case of the Cretaceous rocks, latinised names of the local designations have been adopted in France, and are not unfrequently employed in this country. They are given on pages 325, 326.

It will be seen that, speaking generally, the Jurassic strata of the south-west of England may be regarded as made up of three great masses of limestone, or sandstone, alternating with others of blue clay or shale. The hard limestones and sandstones form well-marked escarpments, which appear in succession beyond that of the chalk, and traverse the country from

N.E. to S.W., as illustrated in the following diagrammatic section.

N.W. Fig. 324. S.E.



Characteristics of the Jurassic fauna and flora.—It appears doubtful if any species of British fossil, whether of the vertebrate or invertebrate class, is common to the Jurassic and Cretaceous. But there is no similar break or discordance as we proceed downwards, and pass from one to another of the several leading members of the Jurassic group, there being often a considerable proportion of the mollusca, sometimes as much as a fourth, common to such divisions as the Upper and Middle Oolite. Between the Lower Oolite and the Lias there is a somewhat greater break, for out of 256 mollusca of the Upper Lias of Britain thirty-seven species only pass up into the Inferior Oolite.

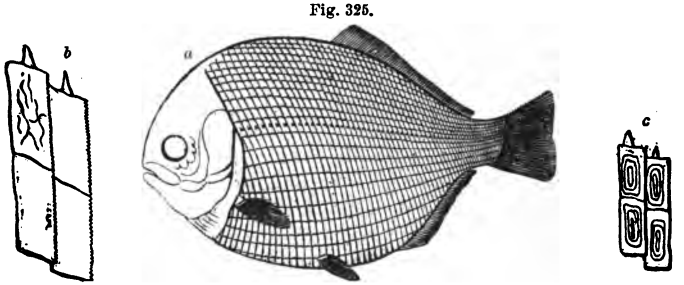
It is in the Jurassic system of strata that we find the most perfect illustration of the Mesozoic marine fauna in the British Islands. Many of the limestones are largely made up of the remains of Foraminifera; and siliceous sponges (Lithistidæ and Hexactinellidæ) are also found. Corals of the order Hexacoralla, both compound and reef-building, like *Isastræa* (fig. 350, p. 228), *Thecosimlia* (fig. 358, p. 294), *Thamnastræa* (fig. 359, p. 294), and simple forms like *Montlivaultia* also abound, and many rocks, like the Coral Rag, are almost entirely made up of the remains of these organisms. Echinoderms are represented by *Apiocrinus* (fig. 366, p. 297) and *Pentacrinus* (fig. 408, p. 307) among the stalked forms (Crinoidea), and by many sea-urchins like *Cidaris*, *Echinobrissus*, *Holectypus*, &c., and some Star-fishes.

The Brachiopoda show the same abundance and variety as in the Cretaceous system. In addition to the Terebratulidæ (fig. 388, p. 302) and Rhynchonellidæ (fig. 389, p. 302), we find a few surviving forms of the Palæozoic Spiriferidæ (fig. 409, p. 307). The Lamellibranchiata are represented by abundant species of Oysters (figs. 353, 356, 360, 386, 396), and also the forms known as *Exogyra* and *Gryphæa* (fig. 403, p. 306), together with many species of *Lima* (fig. 405), *Pecten*, *Modiola*, *Gervillia*, and *Cardium* (fig. 354, p. 293). Of *Trigonia* many very interesting forms occur in different divisions of the Jurassic system (fig. 351, p. 293); and the same is true of the genera *Pholadomya* (fig. 390, p. 302), *Goniomya*, and *Myacites*. Among the Gastro-

poda some of the most abundant genera are *Pleurotomaria* (figs. 391, 392, p. 303), *Nerinæa* (fig. 361, p. 294), *Pterocera*, and *Cylindrites* (fig. 371, p. 298).

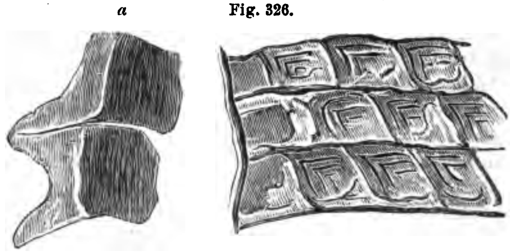
It is by the abundance and richness of its Cephalopod fauna that the Jurassic rocks are best characterised. Ammonites belonging to the genera *Aspidoceras*, *Perisphinctes*, *Cosmoceras* (fig. 364, p. 295), *Macrocephalites*, *Stephanoceras* (figs. 368, 394, 395), *Harpoceras*, *Amaltheus* (fig. 398), *Phylloceras*, *Ægoceras* (fig. 401), and *Arictites* (fig. 400), are particularly abundant and characteristic. The persistent genus *Nautilus* is still represented

Fig. 325.



b. Scales of *Æchmodus Leachii*, Ag. *a.* *Æchmodus.* Restored outline. *c.* Scales of *Dapedius monilifer*, Ag.

a Fig. 326.



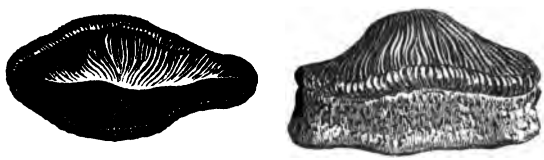
Scales of *Lepidotus gigas*, Ag.
a. Two of the scales detached.

by many forms; and Belemnites of many varieties, some short and stout, and others very slender and several feet in length, are found in nearly all the beds; some of the Belemnites still retain in their fossil state the ink-bag, the contents of which were employed to darken the waters, so that they might escape from their enemies.

In a few finely laminated rocks, like the Stonesfield slate, the septaria of the Lias, and the lithographic limestone of Solenhofen, abundant remains of Crustaceans, both long-tailed and short-tailed, have been found.

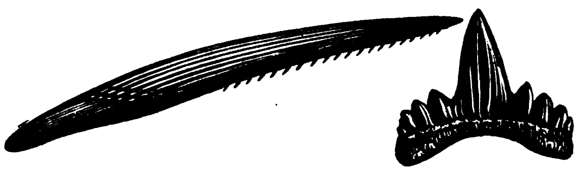
Fish remains are very numerous in some of the Jurassic strata; Ganoids, for the most part with homocercal tails, abound (figs. 325, 326), as do also Selachians like *Hybodus* (fig. 328) and *Acrodus* (fig. 327). The palatal teeth and fin-spines (ichthyodorulites) of Selachian fish are found in many of the Oolitic and Liassic strata.

Fig. 327.



Acrodus nobilis, Ag. (tooth); commonly called 'fossil leech.'
Lias, Lyme Regis and Germany, nat. size.

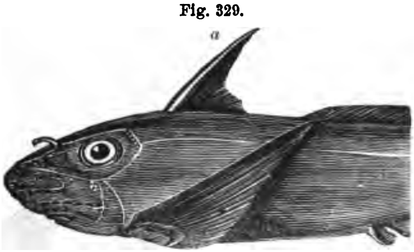
Fig. 328.



Hybodus reticulatus, Ag. Lias, Lyme Regis.
a. Part of fin, commonly called an Ichthyodorulite. *b*. Tooth.

The manner in which the ichthyodorulite supports the fin is illustrated by the following sketch of a living Selachian.

Fig. 329.



Chimæra monstrosa, L.
a. Spine forming anterior part of the dorsal fin.

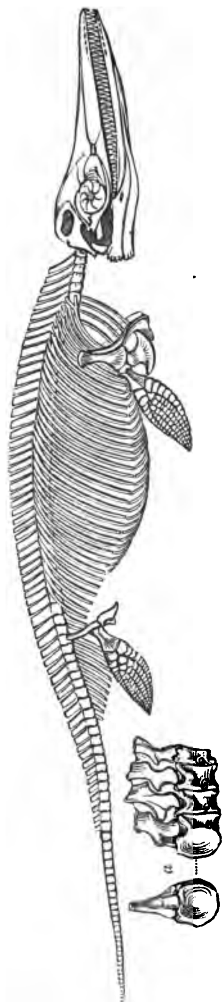
Ordinary bony fishes (Teleosteans) are almost unknown.

The highest organisms found in the Jurassic seas were the remarkable and gigantic reptiles belonging to the orders Plesiosauria (fig. 331) and Ichthyosauria (fig. 330).

Of these extinct reptiles, some of which are between twenty

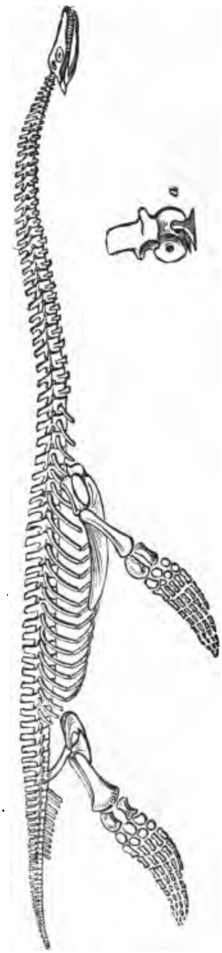
and thirty feet in length, we find skeletons illustrating every stage of development. Occasionally even the outer integument

Fig. 330.



Skeleton of *Ichthyosaurus communis*, Conyb., restored by Conybeare and Cuvier.
a. Costal vertebræ.

Fig. 331.

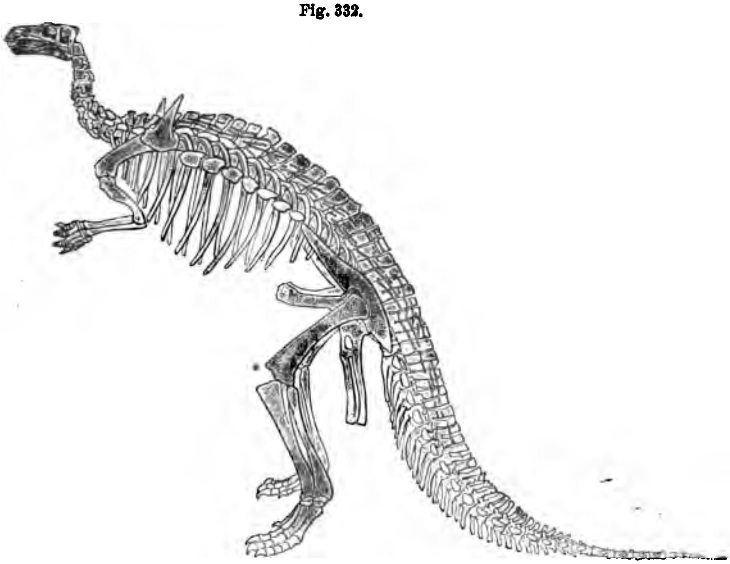


Skeleton of *Plesiosaurus dolichodeirus*, Conyb., restored by Rev. W. D. Conybeare.
a. Cervical vertebra.

of the animals has been preserved, with the contents of their stomachs and their excrement (coprolites).

Of the freshwater and terrestrial fauna and flora we have less perfect but very interesting evidence. In the Purbecks and other similar beds, intercalated with the Jurassic marine series, we find many characteristic forms of freshwater mollusca, crustaceans, and fish. Insects in great variety and of remarkable forms occur in some of the fine-grained deposits. Reptilia belonging to the living orders Lacertilia, Crocodilia, and Chelonia abound; and with these occur many remarkable types now extinct, some of which attained enormous dimensions. Among these were the Dinosauria, a great extinct reptilian order, exhibiting, as Professor Huxley and other comparative anatomists have pointed out, very remarkable affinities with birds. Some of the earlier representatives of the order were of moderate size and were covered with a bony armour, while they exhibit less bird-like characters than later forms. Of this type is the *Scelidosaurus* of the Lias (fig. 332).

Fig. 332.



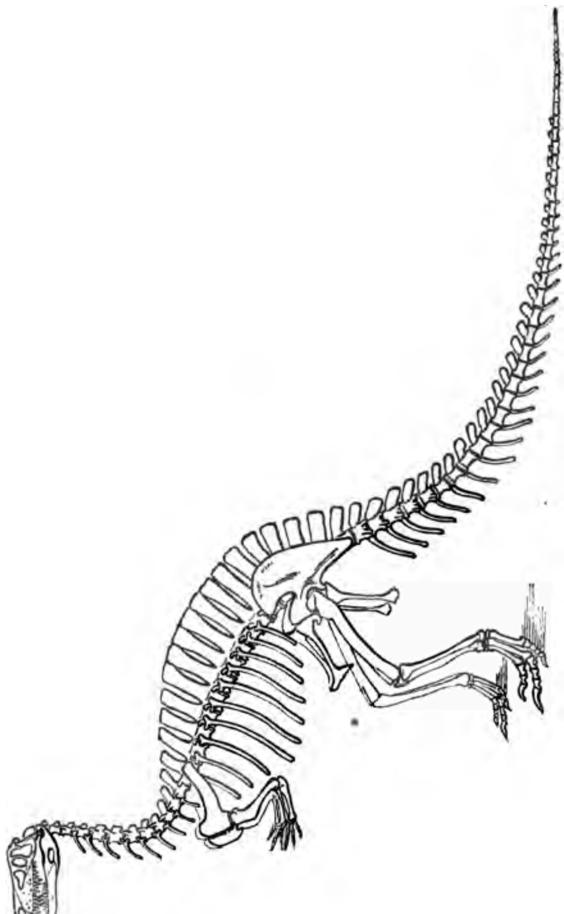
Scelidosaurus Harrisoni, Ow. Restored Skeleton ($\frac{1}{12}$ nat. size). From the Lower Lias of Lyme Regis, Dorsetshire.

A Dinosaurian reptile with its shoulders, back, and tail covered with thick bony scutes or spines. In addition to the three toes on the hind foot, found in the later Dinosaurs, there is a fourth rudimentary one present in this ancient form.

The later bird-like forms were often of gigantic dimensions, like the *Megalosaurus* (fig. 333) and *Iguanodon* (figs. 314–316,

pp. 270, 271). They appear to have walked on their hind legs, and to have left trifid impressions like those of birds.

Fig. 333.

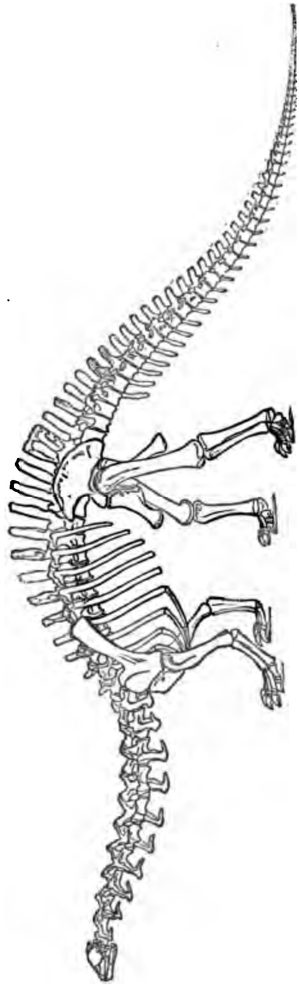


Megalosaurus Bucklandi, Meyer. Skeleton restored about $\frac{1}{100}$ nat. size. From the Great Oolite of Stonesfield.

In the Western Territories of North America, and also in this country, remains are found of a remarkable group of Dinosauria, which are remarkable for their great size and the smallness of their skulls. The reptiles of this group (Atlantosauridæ) did not in all probability assume the erect habit of the Dinosauria before noticed (see fig. 334).

Flying reptiles (Pterosauria) have been found in many Jurassic deposits. In the celebrated lithographic stone of Solen-

FIG. 334.



Brontosaurus excelsus, Marsh. Restored skeleton from the Jurassic of Colorado, U.S. (about $\frac{1}{150}$ nat. size).
The small size of the skull in proportion to the body is very remarkable.
The restoration is by Professor O. C. Marsh, who has furnished this woodcut.

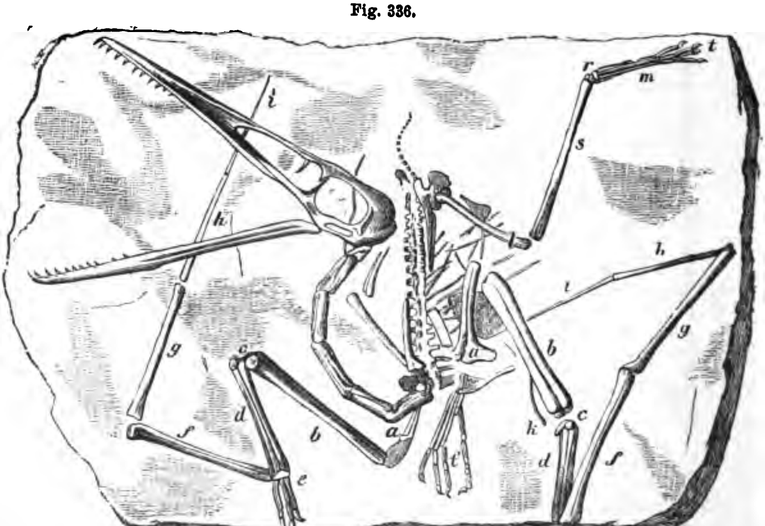
hofen, in Bavaria, which is of about the same geological age as our Kimeridge Clay, we find not only the delicate hollow bird-like bones preserved, but also impressions of the mem-

branes that formed the wings and rudder-like tail. These have enabled Professor Marsh to make the following interesting restoration of the animal.

Fig. 335.

Rhamphorhynchus Muensteri, Goldf. (Restored by Marsh.) ⅐ nat. size.
From the Lithographic Stone, Eichstadt, Bavaria. Woodcut furnished by Prof. O. C. Marsh.

Fig. 336.

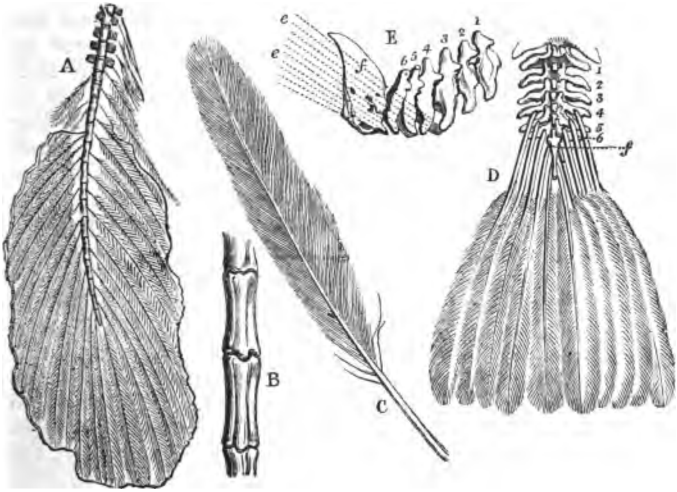


Pterodactylus antiquus, Sömmerring. Almost complete skeleton, ½ nat. size.
From Lithographic Stone of Eichstadt, Bavaria.

f, g, h, i. Modified digits of fore-arm, supporting wing-membrane. *e.* Other digits of fore-arm forming claw. *s, r.* Hind leg with feet (*m, t*).

In the same stone of Solenhofen two examples have been met with of a true bird with teeth, almost entire, and having even the feathers so well preserved, that the vanes as well as the shaft are seen. It has been called by Professor Owen *Archæopteryx macrura.* Although anatomists agree that it is a true bird, yet they also find that in the length of the bones of the tail, and some other minor points of its anatomy, it approaches more nearly to

Fig. 337.



Tail and feather of *Archæopteryx*, from Solenhofen, and tail of living bird for comparison.

A. Caudal vertebr of *Archæopteryx macrura*, Ow.; with impression of tail feathers, ½ nat. size.
B. Two caudal vertebræ of same, nat. size.
C. Single feather, found in 1861 at Solenhofen, by Von Meyer, and called *Archæopteryx lithographica.* Nat. size.
D. Tail of recent vulture (*Gyps bengalensis*, Gm.), showing attachment of tail-feathers in living birds. ¼ nat. size.
E. Profile of caudal vertebræ of same, ⅓ nat. size. *e, e.* Direction of tail-feathers when seen in profile. *f.* Ploughshare bone or broad terminal joint (seen also in *f*, D).

reptiles than does any living bird. In the living representatives of the class Aves, the tail-feathers are attached to a coccygeal bone, consisting of several vertebræ united together; whereas in the *Archæopteryx* the tail is composed of twenty vertebræ, each of which supports a pair of quill feathers. (See fig. 337.)

The first specimen of this oldest known and most remarkable bird is preserved in the British Museum. A second specimen of *Archæopteryx*, which has been discovered at Solenhofen and is

preserved in the Berlin Museum, shows the skull; and the jaws are seen to be armed with conical teeth which are set in sockets, like those of the Cretaceous birds already described, fig. 338.

Fig. 338.

Archæopteryx macrura, Ow. Skull with teeth, nat. size. From Solenhofen.

In the Jurassic rocks a number of lower jaws and a few other bones have been found belonging to mammalia of the primitive order Allotheria, with others that have been referred by zoologists to the Marsupialia. They are all of small size, indicating the existence of animals with dimensions between those of rats and rabbits. They have been chiefly found in the Stonesfield slate and Purbeck beds of England, the Solenhofen stone of Bavaria, and the Upper Jurassic of North America.

In the Jurassic flora we miss the numerous flowering plants (Phanerogamia) of the Cretaceous and Tertiary; but Conifers, Cycads (fig. 346, p. 291), and also Cryptogams occur in great abundance.

The researches of the late Professor Neumayr have proved that there existed in Jurassic times not only a distribution of the forms of marine and terrestrial life in geographical provinces (similar to, but quite distinct from those of the present day), but that also, as in the case of existing fauna and flora, the influence of climate upon this distribution can be distinctly traced at this early period of the earth's history.

British Representatives of the Jurassic System.—It was in the British Isles that the subdivisions of the Jurassic strata were first worked out by William Smith, and many of the names still applied to these strata are taken from English localities.

The Oolitic strata of the south of England consist of deposits of shelly and often oolitic limestones alternating with beds of clay, marl, and sand.

The Upper Oolite.—This division consists of the estuarine Purbeck, with the marine Portlandian and Kimeridge beds below.

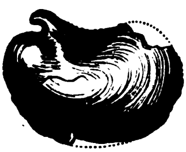
Purbeck beds.—These strata, which we class as the uppermost member of the Jurassic, are of limited geographical extent in Europe, but they acquire importance when we consider the succession of three distinct sets of fossil remains which they contain. Such repeated changes in organic life must have reference to the history of a vast lapse of ages. The Purbeck beds are finely exposed to view in Durdlestone Bay, near Swanage, Dorsetshire, and at Lulworth Cove and the neighbouring bays between Weymouth and Swanage.

The highest of the three divisions is purely freshwater, the strata, about fifty feet in thickness, containing shells of the existing genera *Paludina*, *Physa*, *Limnæa*, *Planorbis*, *Valvata*, *Cyclas*, *Unio*, with *Cypridæ* and fish. All the species seem peculiar, and among them the *Cypridæ* are very abundant and characteristic.

The freshwater limestone called 'Purbeck Marble,' formerly much used in ornamental architecture in the old English cathedrals of the southern counties, is exclusively procured from this division.

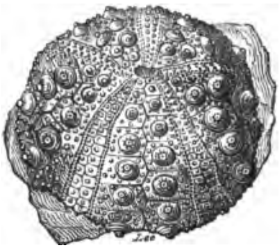
Next in succession is the Middle Purbeck, about thirty feet thick, the uppermost part of which consists of freshwater limestone, with cypridæ, turtles, and fish of different species from those in the preceding strata. Below the limestone are brackish-water beds full of *Cyrena*, and traversed by bands abounding in *Corbula* and *Melania*. These are based on a purely marine deposit, with *Pecten*, *Modiola*, *Avicula*, and *Thracia*. Below this, again, come limestones and shales, partly of brackish and partly of freshwater origin, in which many fish, especially species of *Lepidotus* and *Microdon radiatus*, Ag., are found, and a crocodilian reptile named *Macrorhynchus*. Among the molluscs a remarkable ribbed *Melania*, of the subgenus *Chilina*, occurs.

Fig. 339.



Ostrea distorta, Sow., nat. size. Cinder-bed, Middle Purbeck.

Fig. 340.



Hemicidaris purbeckensis, E. Forbes, nat. size. Middle Purbeck.

Immediately below is a great and conspicuous stratum, twelve feet thick, formed of a vast accumulation of shells of *Ostrea distorta*, Sow. (fig. 339), long familiar to geologists under the local name of 'Cinder-bed.' In the uppermost part of this bed Professor Forbes discovered a species of *Hemicidaris* (fig. 340), a genus characteristic of the Oolitic period. It was accompanied by a species of *Perna*. Below the Cinder-bed, freshwater strata are again seen, filled in many places with species of *Cypridea* and with *Valvata*, *Paludina*, *Planorbis*, *Limnæa*, *Physa* (fig. 341), and *Cyclas*, all different from any occurring higher in the series. Thick beds of chert occur in the Middle Purbeck filled with mollusca and *Cypridæ* of the genera already enumerated, in a beautiful state of preservation, often converted into chalcedony. Among these Professor Forbes met with *Gyrogonites* (the spore-vessels of *Chara*), plants never before discovered in rocks older than the Eocene.

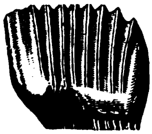
Fig. 341.

Physa Bristovii, E. Forbes. Middle Purbeck.

About twenty feet below the 'Cinder-bed' is a stratum two or three inches thick, in which the fossil mammalia presently to be mentioned occur; and beneath this is a thin band of greenish shales, with marine shells and impressions of leaves like those of a large *Zostera*; it forms the base of the Middle Purbeck.

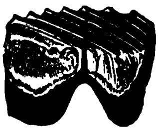
Fossil Mammalia of the Middle Purbeck.—In 1852, after alluding to the discovery of numerous insects and air-breathing

Fig. 342.



Pre-molar of the recent Australian *Hypsiprymnus* (*Potorous*), showing 7 grooves at right angles to the length of the jaw, magnified 3½ diameters.

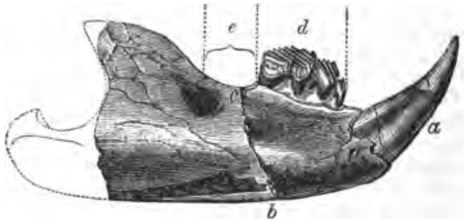
Fig. 343.



Third and largest pre-molar (lower jaw) of *Plagiaulax Becklesii*, Falc., magnified 5½ diameters, showing 7 grooves arranged diagonally to the length of the jaw.

mollusca in the Purbeck strata, Lyell pointed out that, although no mammalia had then been found, 'it was too soon to infer their non-existence from mere negative evidence.' Within the next six years Mr. W. R. Brodie and Mr. S. H. Beckles succeeded in detecting a great number of bones, chiefly lower jaws, in the dirt-bed of the Middle Purbeck, an old terrestrial surface. These have been referred by Professor Owen to twenty-five species belonging to eleven genera.

Fig. 344.



Plagiaulax Becklesii, Falc. Middle Purbeck.
Right ramus of lower jaw, magnified two diameters.

a. Incisor. *b, c.* Line of vertical fracture behind the pre-molars. *d.* Three pre-molars, the third and last (much larger than the other two taken together) being divided by a crack. *e.* Sockets of two missing molars.

The largest pre-molar (see fig. 343) in one fossil genus exhibits seven parallel grooves, producing by their termination a serrated edge in the crown; but their direction is diagonal and not vertical as in the living *Hypsiprymnus*—a distinction, says Dr. Falconer, which is 'trivial, not typical.' As these oblique furrows form so marked a character of the majority of the teeth, Dr. Falconer gave to the fossil the generic name of *Plagiaulax*. The shape and relative size of the incisor, *a*, fig. 344, exhibit a no less striking

similarity to *Hypsiprymnus*. Nevertheless, the more sudden upward curve of this incisor, as well as other characters of the jaw, indicates a great deviation in the form of *Plagiaulax* from that of the living *Hypsiprymnus* or Kangaroo-rat.

There are two fossil specimens of lower jaws of this genus evidently referable to two distinct species extremely unequal in size and otherwise distinguishable. The *Plagiaulax Becklesii*, Falc. (fig. 344), was about as big as the English squirrel or the flying phalanger of Australia (*Petaurus australis*, Waterhouse). The smaller fossil, having only half the linear dimensions of the other, was probably only 1-12th of its bulk. It is of peculiar geological interest, because, as shown by Dr. Falconer, its two back molars bear a decided resemblance to those of the Triassic *Microlestes*, one of the most ancient of known mammalia, of which an account will be given further on.

Up to 1857 all the mammalian remains discovered in Secondary rocks had consisted solely of single branches of the lower jaw, but in that year Mr. Beckles obtained the upper portion of a skull, and on the same slab the lower jaw of another quadruped with eight molars, a large canine, and a broad and thick incisor. It has been named *Triconodon* from its three-coned teeth, and is supposed to have been a small insectivorous mammal, about the size of a hedgehog. Other jaws have since been found, indicating a larger species of the same genus.

To the largest of these Professor Owen has given the name of *Triconodon major*. It was a carnivorous marsupial, rather larger than the Polecat, and equalling probably in size the *Dasyurus viverrinus*, Shaw, of Australia.

Between forty and fifty mandibles, or sides of lower jaws, with teeth, have been found in the Purbecks; and it is remarkable that with these there were no examples of an entire skeleton, or of any considerable number of bones in juxtaposition. When we endeavour to account for the absence of other bones, we are almost tempted to indulge in speculations like those once suggested by Dr. Buckland, when he tried to solve the enigma. 'The corpses,' he said, 'of drowned animals, when they float in a river, distended by gases during putrefaction, have often their lower jaw hanging loose, and sometimes it has dropped off. The rest of the body may then be drifted elsewhere, and sometimes may have been swallowed entire by a predaceous reptile or fish, such as an *Ichthyosaurus* or a Shark.'

Beneath the thin marine band, the base of the Middle Purbeck, some purely freshwater marls occur, containing species of *Cypris*, *Valvata*, and *Limnæa*, different from those of the Middle Purbeck. This is the beginning of the inferior division, which is about 80 feet thick. Below the marls at Mewps Bay, more than 30 feet of brackish-water strata are seen, abounding in a species of *Serpula*, allied to, if not identical with, *Serpula coacervata*, Blum., found in beds of the same age in Hanover. There are also shells of the genus *Rissoa* (of the subgenus *Hydrobia*), and a little *Cardium* of the subgenus *Protocardium*, in these beds, together with *Cypridæ*. Some of the Cypridea-bearing shales are strangely contorted and broken up, at the west end of the Isle of Purbeck. The great dirt-bed or vegetable soil containing the roots and stools of *Cycadeæ*, to be presently described, underlies these marls, and rests upon the lowest freshwater

limestone, a rock about eight feet thick, containing *Cyclas*, *Valvata*, and *Limnæa*, of the same species as those of the uppermost part of the Lower Purbeck, or above the dirt-bed. The freshwater limestone in its turn rests upon the top beds of the Portland stone.

Dirt-bed or ancient surface soil.—A stratum called by quarrymen 'the dirt,' or 'black dirt,' was evidently an ancient vegetable soil. It is from 12 to 18 inches thick, is of a dark brown or black colour, and contains a large proportion of earthy lignite. Through it are dispersed rounded and sub-angular fragments of stone, from 3 to 9 inches in diameter, in such numbers that it almost deserves the name of gravel.

Many silicified trunks of coniferous trees, and the remains of plants allied to *Zamia* and *Cycas*, are buried in this dirt-bed, and must have become fossil on the spots where they grew. The stumps of the trees stand erect for a height of from one to three feet, and even in one instance to six feet, with their roots attached to the soil, at about the same distances from one another as the trees in a modern forest. The carbonaceous matter is most abundant immediately around the stumps, and round the remains of fossil Cycadeæ.

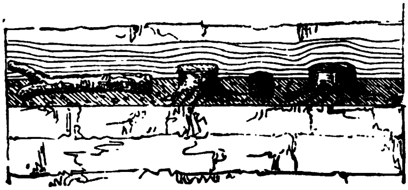
The fragments of the prostrate trees are rarely more than three or four feet in length; but by joining many of them together, trunks have been restored, having a length from the root to the branches of from 20 to 23 feet, the stems being undivided for 17 or 20 feet, and then forked. The diameter of these near the root is usually about one foot, but sometimes as much as 3½ feet. Root-shaped cavities were observed by Professor Henslow to descend from the bottom of the dirt-bed into the subjacent freshwater stone, which, though now solid, must have been in a soft and penetrable state when the trees grew. The thin layers of calcareous shale (fig. 345) were evidently deposited tranquilly, and would have been horizontal but for the protrusion of the stumps of the trees, around the top of each of which they form hemispherical concretions.

There is also at Portland a smaller dirt-bed, six feet below the principal one, six inches thick, consisting of brown earth with upright Cycads of the same species (*Mantellia nidiformis*, Brong., fig. 346) as those found in the upper bed, but no Coniferæ. The weight of the incumbent strata squeezing down the compressible dirt-bed has caused the *Cycads* to assume that form which has led the quarrymen to call them 'petrified birds' nests,' which suggested to Brongniart the specific name of *nidiformis*. The annexed figure shows one of these Purbeck specimens, in which the original cylindrical figure has been less distorted than usual by pressure, and a figure of the living *Cycas* is added (fig. 347) that the student may have an idea of a form so predominant in Mesozoic vegetation.

The dirt-bed is by no means confined to the island of Portland, where it has been most carefully studied, but is seen in the same relative position in the cliffs east of Lulworth Cove, in Dorsetshire, where, as the strata have been disturbed, and are now inclined at an angle of 45°, the stumps of the trees are also inclined at the same angle in an opposite direction—a beautiful illustration of a change in the position of beds originally horizontal (see fig. 348).

From the facts above described we may infer, first, that those beds of the Upper Oolite, called 'the Portland,' which are full of marine shells, were overspread with fluviatile mud, becoming dry land, covered by forest, throughout a portion of the space now occupied by the South of England, the climate being such as to permit the growth of the *Zamia* and *Cycas*; secondly, this land at length sank down and was submerged with its forests beneath a body of fresh water, from which sediment was thrown down enveloping fluviatile shells; thirdly, the regular and uniform preservation of this thin

Fig. 345.



Section in Isle of Portland, Dorset. (Buckland and De la Beche.)

Fig. 346.

Mantellia nidiformis, Brongn.

The upper part shows the woody stem; the lower part the bases of the leaves.

Fig. 347.

Cycas circinalis, L. Living in the East Indies.

Fig. 348.

Section of cliff east of Lulworth Cove. (Buckland and De la Beche.)

bed of black earth, over a distance of many miles, shows that the change from dry land to the state of a freshwater lake or estuary, was not accompanied by any violent denudation, or rush of water, since the loose black earth, together with the trees which lay prostrate on its surface, must inevitably have been swept away had any such violent catastrophe taken place.

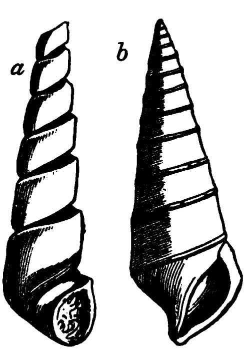
The forest of the dirt-bed was neither the first nor the last which grew in this region. Besides the lower bed containing upright Cycadeæ, just mentioned, another has sometimes been found above it, which implies oscillations in the level of the same ground, and its alternate occupation by land and water more than once.

The plants of the Purbeck beds, so far as our knowledge extends at present, consist chiefly of Ferns, Conifers, and Cycads, without any Dicotyledonous Angiosperms; the whole being more allied to the Jurassic than to the Cretaceous vegetation. The same affinity is indicated by the vertebrate and invertebrate animals. Mr. Brodie has found the remains of insects of the orders Coleoptera, Diptera, Orthoptera, Hemiptera, and Neuroptera, and these orders have modern species, some of which now live on plants, while others hover over the surface of rivers.

Remains of Chelonia, of the genus *Platemys*, of a Crocodile (*Goniopholis*), and Ganoid fish have also been found in the strata.

Portland Oolite and Sand.—The Portland Oolite has already been mentioned as forming, in Dorsetshire, the foundation on which the freshwater limestone of the Lower Purbeck reposes. An interval of time and some change in the physical geography of the area occurred after the deposition of the Portland stone, for it was upheaved and worn and depressed before the Purbecks were deposited upon it. The well-known building-stone of which St. Paul's and so many of the principal edifices of London are constructed is Portland free-stone. About fifty species of mollusca occur in this formation, among which are some Ammonites of large size, such as *Ammonites* (*Perisphinctes*) *giganteus*, Sow. *A.* (*Perisphinctes*) *biplex*, Sow., also occurs. The cast of a spiral univalve called by the quarry-men the 'Portland Screw' (*a*, fig. 349), is common; the shell of the same (*b*) being rarely met with. Also *Trigonia gibbosa*, Sow. (fig. 351) and *Cardium dissimile*, Sow. (fig. 352). This upper member rests on a dense bed of sand, called the Portland sand, containing similar marine fossils, such as *Ostrea expansa*, Sow. (fig. 353), below which is the Kimeridge clay. Corals are rare in this formation, although one species is found plentifully at Tisbury, Wiltshire, in the Portland sand, converted into flint or chert, the original calcareous matter being replaced by silica (fig. 350).

Fig. 349.



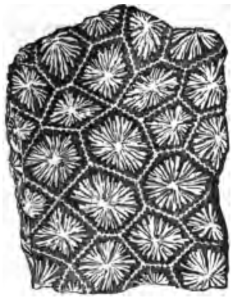
Cerithium portlandicum, Sow. sp., ⅔.
a. Cast of shell known as 'Portland screw.'
b. The shell itself.

The *Kimeridge clay* consists, in great part, of a blue shale,

sometimes becoming highly carbonaceous, and passing into a coaly material (Kimeridge coal). This carbonaceous matter is probably of animal rather than of vegetable origin.

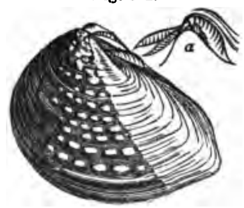
Among the fossils, amounting to nearly 100 species, may be mentioned *Cardium striatulum*, Sow. (fig. 354), and *Ostrea deltoidea*, Sow. (fig. 355), the latter

Fig. 350.



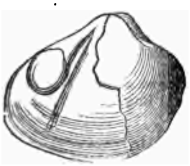
Isastræa oblonga, M. Edw. and J. Haime, mag. 2 diams. Converted into chert from the Portland Sand, Tisbury.

Fig. 351.



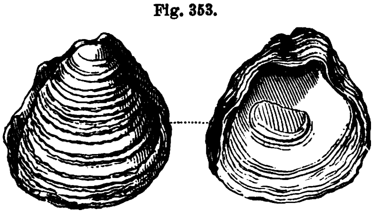
Trigonia gibbosa, Sow. ½ nat. size. *a*. The hinge. Portland Stone, Tisbury.

Fig. 352.



Cardium dissimile, Sow. ¼ nat. size. Portland Stone.

Fig. 353.



Ostrea expansa, Sow. Portland Sand.

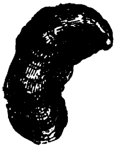
Fig. 354.

Cardium striatulum, Sow., ⅔. Kimeridge Clay, Hartwell.

Fig. 355.

Ostrea deltoidea, Sow. Kimeridge Clay. ¼ nat. size.

Fig. 356.

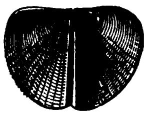


Exogyra virgula, Defr., ⅔. Kimeridge Clay.

found in the Kimeridge clay throughout England and the North of France, and also in Scotland, near Brora. Many Foraminifera occur, and many forms of *Ammonites*. The *Exogyra virgula*, Defr.

(fig. 356), also met with in the Kimeridge clay near Oxford, is so abundant in the Upper Oolite of parts of France, as to have caused the deposit to be termed 'marnes à virgules.' The *Aptychi* of Ammonites (fig. 357) are also widely dispersed through this clay.

Fig. 357.



Aptychus.
Kimeridge Clay.

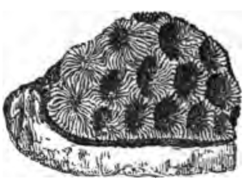
Middle Oolites.—These consist of the Coralline Oolite—beds of limestone, in some places containing many corals—above, and the thick mass of blue clays, known as Oxford clay, below; the base of the series being formed by the sandy stone known as the Kellaways rock.

Coral Rag.—One of the limestones of the Middle Oolite has been called the 'Coral Rag,' because it consists, in part, of beds of fossil corals, some of them retaining the position in which they grew at the bottom of the sea. In their forms they frequently resemble the reef-building corals of the Pacific.

Fig. 358.

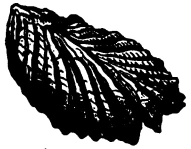
Thecosmilia annularis, Milne Edw., ½; and J. Haime. Coral Rag, Steeple Ashton.

Fig. 359.



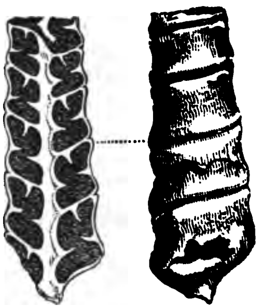
Thamnastræa arachnoides, Park. sp. Coral Rag, Steeple Ashton.

Fig. 360.



Ostrea gregaria, Sow., ½.
Coral Rag, Steeple Ashton.

Fig. 361.



Nerinæa Goodhallii, Sow.
½ nat. size. Coral Rag, Weymouth.

The number of species is small. They belong chiefly to the genera *Thecosmilia* (fig. 358), *Protoseris*, and *Thamnastræa* (fig. 359), and sometimes form masses of coral fifteen feet thick. Echinodermata are numerous, *Cidaris florigemma*, Phil., with species of *Pygurus*,

Pygaster, and *Hemicidaris*, being characteristic. These coralline strata extend through the calcareous hills of the north-west of Berkshire and north of Wilts, and again recur in Yorkshire, near Scarborough. The *Ostrea gregaria*, Sow. (fig. 360), is very characteristic of the formation in England and on the Continent.

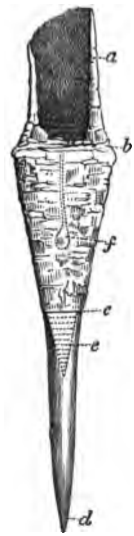
One of the limestones of the Jura, referred to the age of the English coral rag, has been called 'Nerinæan limestone' (Calcaire à Nérinées); *Nerinæa* being an extinct genus of univalve shells (fig. 361), much resembling *Cerithium* in external form and common in the Jurassic rocks. The annexed section shows the curious and continuous ridges on the columella and whorls.

Oxford Clay.—The coralline limestone, or 'coral rag,' above

Fig. 362.

Belemnites hastatus, Blain., $\frac{1}{3}$. Oxford Clay.

Fig. 363.



Belemnites Puzosianus, D'Orb., $\frac{1}{6}$.

Oxford Clay, Christian Malford.

a. Section of the shell projecting from the phragmacone.
b–c. External covering to the ink-bag and phragmacone.
c, *d*. Osselet, or guard, or that portion commonly called the belemnite.
e. Conical chambered body called the phragmacone.
f. Position of ink-bag beneath the shelly covering.

Fig. 364.

Ammonites (*Cosmoceras*) *Jason*, Reinecke. (Syn. *A. Elizabethæ*, Pratt.) Oxford Clay, Christian Malford, Wiltshire.

described, and the accompanying sandy beds, called 'Calcareous grits,' of the Middle Oolite, rest on a thick bed of clay, called the 'Oxford clay,' sometimes not less than 600 feet thick. In this there are no corals, but great abundance of Cephalopoda belonging to the Ammo-

nites and Belemnites. In some of the finely laminated clays, Ammonites are very perfectly preserved, although somewhat compressed, and they are frequently found with the lateral lobe extended on each side of the aperture into a horn-like projection. (See fig. 364.) In the same clays the soft parts of the Belemnite, including the ink-bag, are also found (fig. 363).

Remains of the Reptilian genera *Ichthyosaurus*, *Pliosaurus*, *Plesiosaurus*, *Megalosaurus*, and *Rhamphorhynchus*, are found in the Oxford clay.

Kellaways Rock.—The arenaceous limestone which passes under this name is generally grouped as a member of the Oxford clay, in which it forms, in the south-west of England, lenticular masses, 8 or 10 feet thick, containing at Kellaways, in Wiltshire, numerous casts of Ammonites, and other shells. But in Yorkshire this calcareo-arenaceous formation thickens to about 30 feet, and constitutes the lower part of the Middle Oolite, extending inland from Scarborough in a southerly direction.

The Lower Oolites consist, in the South of England, of a somewhat variable series of deposits which generally retain the names given to them by William Smith. In Yorkshire, however, they are represented by a thick series of sands and clays, with some thin beds of coal, the whole being evidently of estuarine origin, and yielding many interesting remains of land-plants.

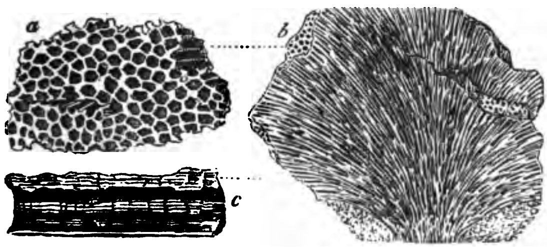
Cornbrash and Forest Marble.—The upper division of this series, which is more extensive than the preceding or Middle Oolite, is called in England the Cornbrash, as being a brashy, easily broken rock, good for corn land. It consists of sandy limestone and clay, which pass downwards into the Forest-marble, an argillaceous limestone, abounding in marine fossils. Brachiopods are very abundant, and the Echinoidea, *Echinobrissus clunicularis*, Llhwyd, *E. orbicularis*, Phil. sp., and *Holectypus depressus*, Lam. sp., and also the bivalve *Avicula echinata*, Sow., are common. In some places, as at Bradford, near Bath, this limestone is replaced by a mass of clay. The sandstones of the Forest-marble of Wiltshire are often ripple-marked and filled with fragments of broken shells and pieces of driftwood, having evidently been formed on a coast. In the same stone the claws of crabs, fragments of Echini, and other signs of a neighbouring beach, are still observed.

Great (or Bath) Oolite.—Although the name of 'coral-rag' has been appropriated, as we have seen, to the highest member of the Middle Oolite before described, some portions of the Lower Oolite are equally entitled in many places to be called coralline limestones. Thus the Great Oolite near Bath contains various corals, among which *Calamophyllia radiata*, Lam. (fig. 365), is very conspicuous, single individuals forming masses several feet in diameter; and having probably occupied much time in growing, like the large existing Brain-coral (*Meandrina*) of the tropics.

Different species of Crinoids, or stone-lilies, are also common in the same rocks with the corals; and, like them, must have lived on a firm bottom, where their base of attachment remained undisturbed, for years (*c*, fig. 366). Such fossils, therefore, are almost confined to the limestones; but an exception occurs at Bradford, near Bath, in the Forest-marble series, where they are enveloped in clay sometimes sixty feet thick. In this case, however, it appears that the solid

upper surface of the 'Great Oolite' had supported, for a time, a thick submarine forest of these beautiful crinoids, until the clear and still water was invaded by a current charged with mud, which threw down the 'stone-lilies,' and broke most of their stems short off

Fig. 365.

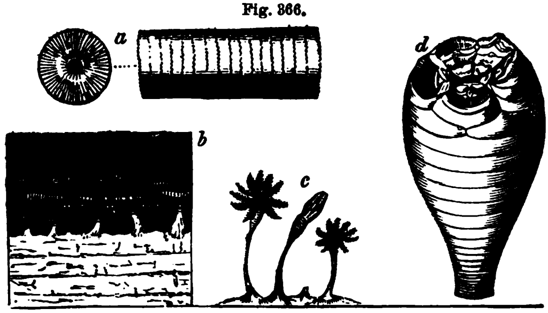


Calamophyllia radiata, Lamouroux.

a. Section transverse to the tubes.
b. Vertical section, showing the radiation of the tubes.
c. Portion of interior of tubes magnified, showing striated surface.

near the point of attachment. The stumps still remain in their original position; but the numerous ossicles, once composing the stem, arms, and body of the encrinite, were scattered at random through the argillaceous deposit, in which some now lie prostrate. These appearances are represented in the section *b*, fig. 366, where

Fig. 366.



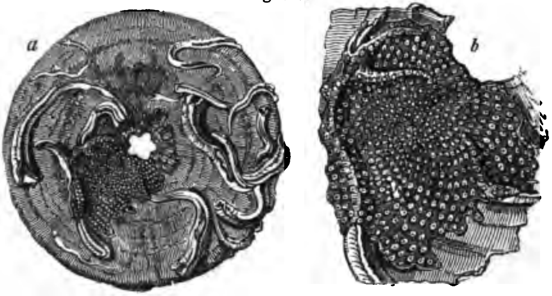
Apiocrinites rotundus, Mill., or Pear Encrinite. Fossil at Bradford, Wilts.

a. Stem of *Apiocrinites*, and one of the articulations, natural size.
b. Section at Bradford of Great Oolite and overlying clay, containing the fossil encrinites.
c. Three perfect individuals of *Apiocrinites*, represented as they grew on the surface of the Great Oolite.
d. Body of the *Apiocrinites rotundus*, Mill. Half nat. size.

the darker strata represent the Bradford clay. The upper surface of the calcareous stone below is completely incrusted over with a continuous pavement, formed by the stony roots or attachments of the Crinoidea; and, besides this evidence of the length of time they

had lived on the spot, we find great numbers of single joints, of the stem and body of the encrinite, covered over with *Serpulæ*. Now

Fig. 367.



a. Single plate of body of *Apiocrinus*, overgrown with *Serpulæ* and *Bryozoa*. Natura size. Bradford Clay.
b. Portion of the same magnified, showing the bryozoan *Diastopora diluviana*, M. Edw., covering one of the *Serpulæ*.

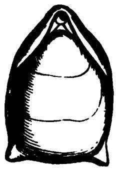
these *Serpulæ* could only have begun to grow after the death of some of the 'stone-lilies,' parts of whose skeletons had been strewed over the floor of the ocean before the irruption of argillaceous mud. In some instances we find that, after the parasitic *Serpulæ* were full grown, they had become incrusted with a bryozoan, called *Diastopora diluviana*, M. Edw. (see *b*, fig. 367), and many generations of these molluscoids had succeeded each other in the pure water, before the whole became fossil.

Fig. 368.

Ammonites (*Stephanoceras*) *macrocephalus*, Schloth. ½ nat. size. Great Oolite and Oxford Clay.

The calcareous portion of the Great Oolite consists of several shelly limestones, one of which, called the Bath Oolite, is much celebrated as a building-stone. In parts of Gloucestershire, especially near Minchinhampton, the Great Oolite, according to Lycett,

Fig. 369.

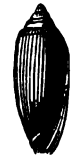


Terebratula digona, Sow., nat. size. Bradford Clay.

Fig. 370.

Purpuroidea nodulata, Y. & B. sp. Young sp., ½ nat. size. Great Oolite, Minchinhampton.

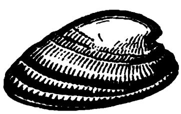
Fig. 371.



Cylindrites acutus, Sow. Syn. *Actæon acutus*, nat. size. Great Oolite, Minchinhampton.

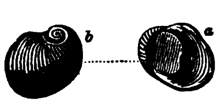
'must have been deposited in a shallow sea, where strong currents prevailed, for there are frequent changes in the mineral character of the deposit, and some beds exhibit false stratification. In others, heaps of broken shells are mingled with pebbles of rocks foreign to the neighbourhood, and with fragments of abraded corals, dicotyledonous wood, and crabs' claws. In such shallow-water beds, shells of the genera *Patella*, *Nerita*, *Rimula*, and *Cylindrites* are common (see figs. 370 to 374); while cephalopods are rare, and, instead of

Fig. 372.



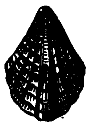
Patella rugosa, Sow., ⅔. Great Oolite.

Fig. 373.



Nerita costulata, Desh., mag. 2 diams. Great Oolite.

Fig. 374.

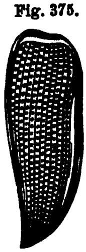


Rimula (*Emarginula*) *clathrata*, Sow., mag. 3 diams. Great Oolite.

Ammonites and *Belemnites*, numerous genera of carnivorous gastropods appear.

Stonesfield Slate: Mammalia.—The slate of Stonesfield was shown by Lonsdale to lie at the base of the Great Oolite. It is a slightly oolitic shelly limestone, forming large lenticular masses embedded in sand; it is only six feet thick, but very rich in organic remains. The remains of *Belemnites*, *Trigoniæ*, and other marine remains, with fragments of wood, are common, and impressions of ferns, Cycadeæ, and Conifers. Portions of insects, also, among which are

Fig. 375.



Elytron of *Buprestis?* nat. size. Stonesfield.

Fig. 376.

Tupaia Tana, Raff.
Right ramus of lower jaw. Natural size.
A recent insectivorous placental mammal, from Sumatra.

the wings of a butterfly, and the elytra or wing-covers of beetles, are perfectly preserved (see fig. 375), some of the latter approaching the genus *Buprestis*. The remains, also, of many genera of reptiles, such as *Ichthyosaurus*, *Pliosaurus*, *Plesiosaurus*, *Cetiosaurus*, *Teleosaurus*, *Megalosaurus*, and *Rhamphorhynchus*, have been discovered in the same limestone.

There have also been discovered no less than ten specimens of lower jaws of marsupial mammiferous quadrupeds, belonging to four different genera, for which the names of *Amphitherium* (figs. 381, 382), *Amphilestes*, *Phascolotherium*, and *Stereognathus* have been adopted.

The second mammiferous genus discovered in the same slates was named originally by Mr. Broderip *Didelphys Bucklandi* (see fig. 383), and has since been called *Phascolotherium* by Owen.

Fig. 377.

Fig. 378.

Part of lower jaw of *Tupaia Tana*, Raff. Twice natural size.

Fig. 377. End view seen from behind, showing the very slight inflection of the angle at *c*.

Fig. 378. Side view of same.

Fig. 379.

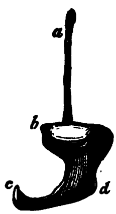
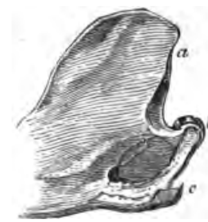


Fig. 380.



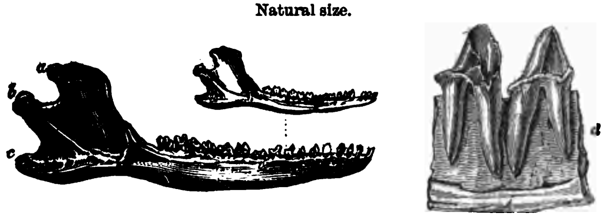
Part of lower jaw of *Didelphys Azaræ*, Temm.; recent, Brazil. Natural size.

Fig. 379. End view seen from behind, showing the inflection of the angle of the jaw, *c*, *d*.

Fig. 380. Side view of same.

Fig. 381.

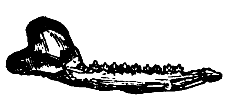
Natural size.



Amphitherium Prevostii, Cuv. sp. Stonesfield Slate.
Syn. *Thylacotherium Prevostii*, Valenc.

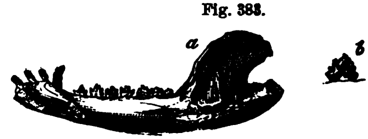
a. Coronoid process. *b*. Condyle. *c*. Angle of jaw. *d*. Double-fanged molars.

Fig. 382.



Amphitherium Broderipii, Ow. Natural size. Stonesfield Slate.

Fig. 383.



Phascolotherium Bucklandi, Brod. sp.
a. Natural size. *b*. Molar of same, magnified.

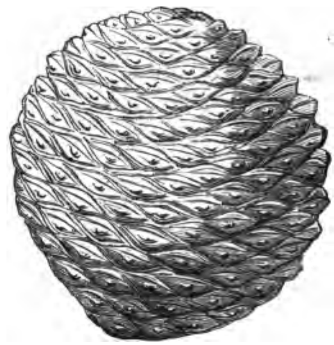
In 1854 the remains of another mammifer, small in size, but larger than any of those previously known, was brought to light. The generic name of *Stereognathus* was given to it, and, as is usually the case in these old rocks, it consisted of part of a lower jaw, in which were implanted three double-fanged teeth, differing in structure from those of all other known recent or extinct mammals.

Plants of the Slate.—At least twelve genera of ferns are found, *Pecopteris*, *Sphenopteris*, and *Tæniopteris* being common; also *Palæozamia*, a Cycad, and the Conifer *Thuyites*. The Araucarian pines, which are now abundant in Australia and its islands, together with marsupial quadrupeds, are found in like manner to have accompanied the marsupials in Europe during the Oolitic period. In the same rock, endogens of the most perfect structure are met with, as, for example, fruits allied to the

Fig. 384.

Portion of a fossil fruit of *Podocarya Bucklandi*, Ung., magnified. (Buckland's Bridgw. Treatise, pl. 63.) Inferior Oolite, Charmouth, Dorset.

Fig. 385.



Cone of fossil *Araucaria Sphærocarpa*, Carr. Inferior Oolite. Bruton, Somersetshire. ½ diameter of original. In the collection of the British Museum.

Pandanus, such as the *Kaidacarpum ooliticum* of Carruthers in the Great Oolite and the *Podocarya* of Buckland (see fig. 384) in the Inferior Oolite.

Fuller's Earth.—Between the Great and Inferior Oolite in the West of England, an argillaceous deposit, called 'the Fuller's earth,' occurs; but it is wanting in the North of England. It abounds in the small oyster represented in fig. 350. The number of mollusca known in this deposit is about seventy; namely, fifty Lamellibranchiate Bivalves, ten Brachiopods, three Gasteropods, and seven or eight Cephalopods; most of them are common to the Great Oolite above or the Inferior Oolite below.

Fig. 386.

Ostrea acuminata, Sow. Fuller's Earth. ½ nat.

Inferior Oolite.—This formation consists of calcareous freestones and shelly limestones, attaining in some places, near Cheltenham, a thickness of 269 feet. It rests conformably on the Lias, and many species pass from this lower to the upper formation. It sometimes rests upon yellow sands, formerly classed as the sands of the Inferior Oolite, but now regarded, in part at least, as a member of the Upper Lias. These Midford sands repose upon the Upper Lias clays in the South and West of England. The Collyweston slate, and Lincolnshire limestone, formerly classed with the Great Oolite, and supposed to represent the Stonesfield slate, and Bath freestones, are now found to belong to the Inferior Oolite. The Collyweston beds, on the whole, assume a much more marine

character than the Stonesfield slate. Nevertheless, one of the fossil plants (*Aroides Stutterdi*, Carr), remarkable, like the Pandanaceous species before mentioned (fig. 348), as a representative of the monocotyledonous class, is also common to the Stonesfield beds in Oxfordshire.

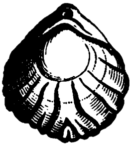
The Inferior Oolite of Yorkshire (800 feet) consists largely of shelly limestones, shales, ironstones, and sandstones, which assume

Fig. 387.

Hemitelites Brownii, Goepp. Syn. *Phlebopteris contigua*, Lind. and Hutt. Lower carbonaceous strata, Inferior Oolite shales. Gristhorpe, Yorkshire.

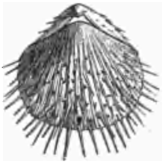
much the aspect of a true coal-field, thin seams of coal having actually been worked in them for more than a century. A rich harvest of fossil ferns has been obtained from them at Gristhorpe, near Scarborough (fig. 387). The strata contain many Cycadeæ, of which family a magnificent specimen has been described by Prof. Williamson under the name *Zamia gigas*, and a fossil called *Equisetum columnare*, Brong., which maintains an upright position in sandstone strata over a wide area. Shells of *Estheria* and

Fig. 388.



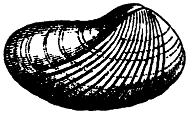
Terebratula fimbria, Sow., ½. Inferior Oolite marl. Cotswold Hills.

Fig. 389.



Rhynchonella spinosa, Schloth, ⅔. Inferior Oolite.

Fig. 390.



Pholadomya fidicula, Sow., ½ natural size. Inferior Oolite.

Unio, collected by Bean and others from these Yorkshire coal-bearing beds, point to the estuarine or fluviatile origin of the deposit.

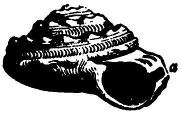
At Brora, in Sutherlandshire, a coal-seam probably coeval with the above, or at least older than the Kellaways Rock, the lowest marine bed of the Middle Oolitic period, was extensively mined nearly a century ago. It affords the thickest stratum of pure vegetable matter hitherto detected in any secondary rock in England,

upwards of 80,000 tons having been extracted. One seam of coal of good quality, $3\frac{1}{2}$ feet thick, has lately been worked, but it is very pyritous. The roof-bed of the coal is literally composed of marine

Fig. 391.

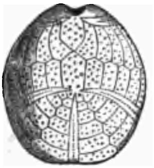
Pleurotomaria granulata, Sow., ½. Ferruginous Ool., Normandy. Inferior Oolite, England. Under side.

Fig. 392.



Pleurotomaria ornata, Sow. sp. Inferior Oolite. ½ nat. size.

Fig. 393.

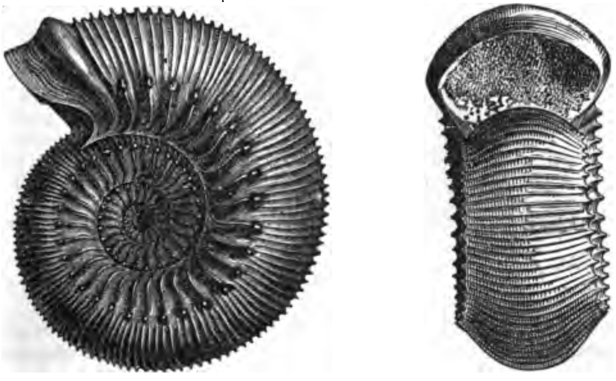


Collyrites (Dysaster) ringens, Agass. Inf. Ool., Somersetshire.

shells, such as *Pholadomya, Trigonia, Goniomya, Pteroperna, Cerithium*, &c.

Among the characteristic shells of the Inferior Oolite may be instanced *Terebratula fimbria*, Sow. (fig. 388), *Rhynchonella spinosa*, Schloth (fig. 389), and these two genera predominate over other Brachiopoda. *Pholadomya fidicula*, Sow. (fig. 390), is found; and the genus *Pleurotomaria* is also a form very common in this division as well as in the Jurassic system generally. It resembles *Trochus* in

Fig. 394.



Ammonites (Stephanoceras) Humphresianus, Sow., ½. Inferior Oolite.

form, but is marked by a deep cleft (*a*, figs. 391, 392) on one side of the aperture. The *Collyrites (Dysaster) ringens*, Ag. (fig. 393), is an Echinoderm common to the Inferior Oolite of England and France, as are the two *Ammonites* (figs. 394, 395). The important

Ammonites are *A.* (*Parkinsonia*) *Parkinsoni*, Sow., *A.* (*Stephanoceras*) *Humphresianus*, Sow., *A.* (*Hammatoceras*) *Sowerbyi*, Mills, and *A.* (*Ludwigia*) *Murchisonæ*, Sow.

Fig. 395.

Ammonites (*Stephanoceras*) *Braikenridgii*, Sow., ½. Oolite, Scarborough. Inferior Oolite, Dundry; Calvados, &c.

Fig. 396.

Ostrea Marshii, Sow. ½ nat. Middle and Lower Oolite.

The Upper Lias.—The lower portion of the Jurassic system is known as the Lias, and it consists of three divisions. The Upper *Lias* consists of dark blue clays, containing some septaria, and passes upwards into beds of sand, and downwards into harder nodular bands, which sometimes contain the remains of fish and insects. The blue clays are sometimes highly pyritous, and in York-

Fig. 397.

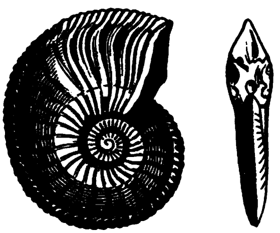
Ammonites (*Hildoceras*) *bifrons*, Brug. *A. Walcotii*, Sow., ½. Upper Lias shales.

shire were formerly used for the manufacture of alum; they also contain masses of wood converted into jet. The most common fossils of the Upper Lias are *Ammonites* (*Stephanoceras*) *communis*, Sow., *Am.* (*Harpoceras*) *bifrons*, Brug. (fig. 397), *Am.* (*Harpoceras*) *serpentinus*, Rein., *Am.* (*Phylloceras*) *heterophyllus*, Sow., and *Leda ovum*, Sow.

The Middle Lias consists of a ferruginous limestone full of shells, known as the Marlstone rock-bed; this rock sometimes passes into an ironstone. The valuable iron ores of Cleveland, in the North

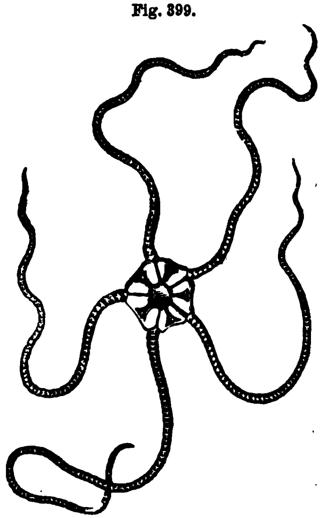
of Yorkshire, are of this age, and consist of oolitic limestones which have been more or less completely converted into masses of ferrous carbonate. Fossils are very abundant in the Middle Lias, amongst the most characteristic being *Ammonites* (*Amaltheus*) *spinatus*, Brug., *Am.* (*Amaltheus*) *margaritatus*, Montf. (fig. 398), *Am.* (*Ægoceras*) *Henleyi*, Sow., *Am.* (*Ægoceras*) *capricornis*, Schloth, with *Pecten æquivalvis*, Sow., and *Rhynchonella tetrahedra*, Sow. Among the most beautiful of the fossils of this division we may instance the fine Ophiurid (Brittle Starfish) *Palæocoma tenuibrachiata*, E. Forbes (fig. 399).

Fig. 398.



Ammonites (*Amaltheus*) *margaritatus*, Montf. Syn. *A. Stokesii*, Sow.; *A. Clevelandicus*, Y. and B. Middle Lias. ½.

Fig. 399.



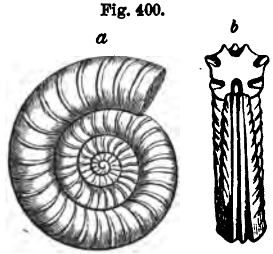
Palæocoma (*Ophioderma*) *tenuibrachiata*, E. Forbes. Middle Lias, Seatown, Dorset.

The Lower Lias consists in its upper part of thick beds of shale, and in its lower of numerous alternations of shale and shelly limestone, the latter being replaced at the base of the series by compact argillaceous limestones, which are largely employed in the manufacture of hydraulic cements. In North Lincolnshire, at Scunthorpe and Froddingham, the shelly limestones of the Lower Lias are found to be converted into ferrous carbonate, which is worked as an iron ore.

In all the divisions of the Lias and Oolite we are able to recognise the existence of a succession of *Zones*, each of which is distinguished by a characteristic assemblage of fossils. These zones, although so clearly recognisable by their fossil contents, appear usually to pass insensibly into one another, and are not necessarily distinguished by any changes in the mineral characters of the strata. The zones are named after one of the most striking of the fossils which it contains, and in the case of the Mesozoic rocks, species of Ammonites are usually selected for the purpose. In the Lower Lias the succession of zones is especially distinct and well marked.

The commonest Ammonites of the Lower Lias are *Amaltheus oxynotus*, Quenst., *Arietites obtusus*, Sow., *A. Turneri*, Sow. *A.*

Fig. 400.



Ammonites (*Arietites*) *Bucklandi*, Sow. (*A. bisulcatus*, Brug.) ⅛ diameter of original.

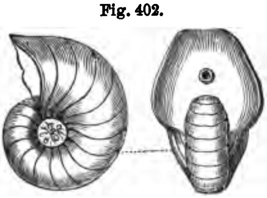
a. Side view. *b*. Front view, showing mouth and bisulcated keel. Characteristic of the Lower Lias of England and the Continent.

Fig. 401.

Am. (*Ægoceras*) *planorbis*, Sow. ½ diameter of original.

From the base of the Lower Lias of England and the Continent.

Fig. 402.

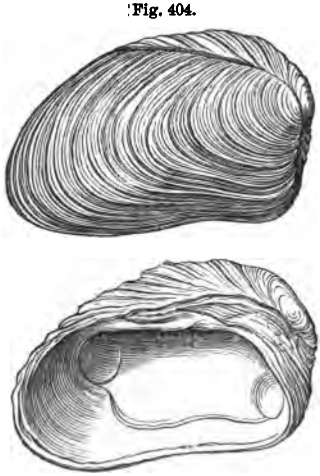


Nautilus truncatus, Sow. Lias. ⅙ nat. size.

Fig. 403.

Gryphæa incurva, Sow. (*G. arcuata*, Lam.) ½. Lias.

Fig. 404.



Hippopodium ponderosum, Sow., ¼ diameter. Lias, Cheltenham.

Fig. 405.

Lima gigantea, Sow., ⅓. Lias.

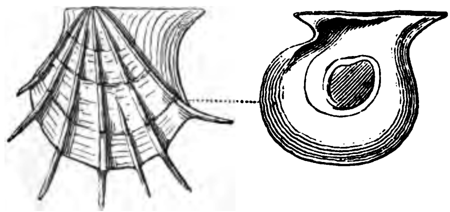
Bucklandi, Sow. (fig. 400), with *Ægoceras angulatus*, Sow., and *Æ. planorbis*, Sow. (fig. 401). Belemnites of many species abound, and examples of the persistent type Nautilus are not rare (fig. 402).

Among other very common fossils of the Lower Lias are *Gryphæa arcuata*, Lam. (*G. incurva*, Sow.) (fig. 403), *Lima gigantea*, Sow. (fig.

Fig. 406.

Avicula inæquivalvis, Sow., ⅔. Lower Lias.

Fig. 407.



Avicula cygnipes, Phil., ½. Lower Lias, Gloucestershire and Yorkshire.
a. Lower valve. *b*. Upper valve.

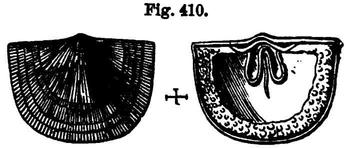
Fig. 408.

Extracrinus (*Pentacrinus*) *Briareus*, Mill., ½ natural size.
(Body, arms, and part of stem.)
Lower Lias, Lyme Regis.

Fig. 409.

Spiriferina Walcotii, Sow., ½.
Lower Lias.

Fig. 410.



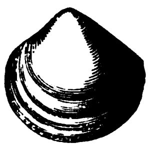
Leptæna Moorei, Dav.
Upper Lias, Ilminster.

405), *Avicula inæquivalvis*, Sow. (fig. 406), and *A. cygnipes*, Phil. (fig. 407), *Hippopodium ponderosum*, Sow. (fig. 404), with *Spiriferina Walcotii*, Sow. (fig. 409), and the minute *Leptæna Moorei*, Dav. (fig. 410).

The ossicles of the beautiful crinoid Pentacrinus, of which a very perfect example is represented above, also abound in the Lower Lias.

White Lias and Rhætic Strata.—Beneath the Lower Lias just described, we find at certain localities beds of a cream-coloured limestone (called the White Lias by William Smith), under which occur black pyritous shales and sandstones with an interesting assemblage of marine mollusca, some of the most characteristic of which are represented below.

Fig. 411.



Cardium rhæticum, Merrian. Nat. size. Rhætic Beds.

Fig. 412.

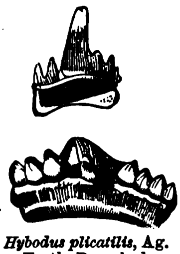
Pecten valoniensis, Dfr. ½ nat. size. Portrush, Ireland, &c. Rhætic Beds.

Fig. 413.

Avicula contorta, Portlock. Portrush, Ireland, &c. Nat. size. Rhætic Beds.

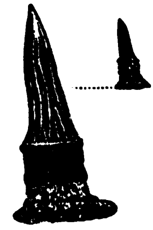
In the midst of these black shales is found a band almost made up of the bones and teeth of fish and saurians. Some of the fish remains are identical with forms found in the Trias of Germany.

Fig. 414.



Hybodus plicatilis, Ag. Teeth, Bone-bed. Aust and Axmouth.

Fig. 415.



Saurichthys apicalis, Ag. Tooth; natural size and magnified. Axmouth.

Fig. 416.

Gyrolepis tenuistriatus, Ag. Scale: nat. size and magnified. Axmouth.

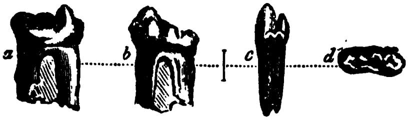
These strata, which are of insignificant thickness and are known by the names of the Zone of *Avicula contorta*, Portl., the Infra Lias, and the Penarth beds, are of great interest as representing what in the Alpine district constitutes a great formation, several thousands of feet in thickness, known as the Rhætic system, which appears to completely bridge over the interval between the Jurassic and Triassic systems.

In England, Germany, and North America, teeth of a minute mammal, nearly the oldest as yet known, have been found. The British and German form is known as *Microlestes* (fig. 417), and the American as *Dromatherium*.

Freshwater and terrestrial deposits of Jurassic age are found in

this country represented by the Purbecks of the South of England, the sandstones and shales with thin beds of coal of Lower Oolite age of Yorkshire, and various estuarine and freshwater beds which

Fig. 417.

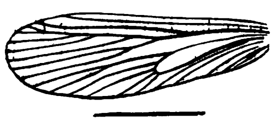


Microlestes antiquus, Plieninger. Molar tooth, magnified. Rhætic Diegerloch, near Stuttgart, Würtemberg.

a. View of inner side ? *b.* Same, outer side ?
c. Same in profile. *d.* Crown of same.

alternate with marine strata, from the Lias to the Upper Oolite inclusive, on the east coast of Sutherland. Similar strata attain a great thickness on the west coast of Scotland and the Inner Hebrides. Even in the English Lias, at the base of the Upper and Lower divisions respectively, we find beds crowded with the remains of insects, small crustaceans, and fish—with occasional marine brackish-water and even freshwater shells—which have pro-

Fig. 418.



Wing of a neuropterous insect, from the Lower Lias, Gloucestershire. (Rev. P. B. Brodie.)
The line below the figure indicates the length of the object.

bably been formed in shallow-water lagoons close to the land. The exquisite preservation of some of the insect remains discovered and described by the Rev. P. B. Brodie is illustrated by the accompanying figure.

The classification of the Jurassic strata of this country was established on a sound basis by William Smith in 1815. The labours of Marcou in France, of Oppel and Quenstedt in Germany, and of Dr. Wright in this country, have shown how widespread and distinctive are the various zones in this system of stratified rocks. The Jurassic rocks of Yorkshire have been described in the 'Geology of Yorkshire' of the late Professor John Phillips, and those of the South of England in the 'Geology of Oxford' of the same author. The correlation of the northern and southern types of Jurassic rocks in this country has been discussed in the Geological Survey Memoir on Rutland (1875) More recently, the Geological Survey has published a series of Memoirs dealing with the same subject, entitled 'The Jurassic Rocks of Britain,' by C. Fox-Strangways and H. B. Woodward.

CHAPTER XVIII

THE TRIASSIC SYSTEM

Subdivisions of the Trias in England—Corals, Echinodermata, Brachiopoda, Lamellibranchiata, Gastropoda, and Cephalopoda of the Trias—Fish, Amphibians, and Reptiles—Terrestrial Flora of the Trias—Triassic Mammalia—The Keuper and its Reptilia—The Dolomitic Conglomerate—Elgin Sandstones—The Bunter Formation of Red Sandstones and Clays—Rock-salt, Gypsum, &c.

Nomenclature and Classification of the Triassic Strata. The name of Trias was first given to this great division of the Geological Series by the Germans, from the circumstance that, in Central Europe, the system consists of three members. The uppermost of these is called the Keuper (from the name given in Coburg to a kind of particoloured cloth), the middle is known as the Muschelkalk (shelly limestone), while the lowest receives the name of Bunter (variegated). The term 'Trias' is now almost universally employed for the strata of this age, though the French sometimes apply to it the name of 'Saliferous,' owing to its containing important deposits of rock-salt. In the British Islands, the Triassic strata bear so close a general resemblance to those of Permian age, which underlie them, that the older writers grouped these two formations together as 'New Red Sandstone,' the name being given in recognition of the fact that the coal-bearing strata are underlain by red and variegated beds of Devonian age (*Old* Red Sandstone) and overlain by others of Permian and Triassic age (*New* Red Sandstone). Conybeare and De la Beche proposed to designate the whole of the New Red Sandstone as Poikilitic, on account of the variegated tints of its strata.

In Britain and the greater part of France the middle division of the Trias—the Muschelkalk—is absent, and the system consists only of two members, the Bunter (or Grès bigarré of French authors) and the Keuper (or Marnes irisées of the French).

The general order of succession in the Trias of Britain and the comparison of its subdivisions with equivalent strata on the continent of Europe are shown in the following table.

NOMENCLATURE OF TRIAS

German	French	English
Keuper	Marnes irisées	Red and grey saliferous and gypseous shales and sandstone, with rock salt. Dolomitic conglomerate.
Muschelkalk	Muschelkalk, ou calcaire coquillier	Wanting in England.
Bunter-Sandstein.	Grès bigarré	Red sandstone and pebble beds and quartzose conglomerate. Soft red sandstones.

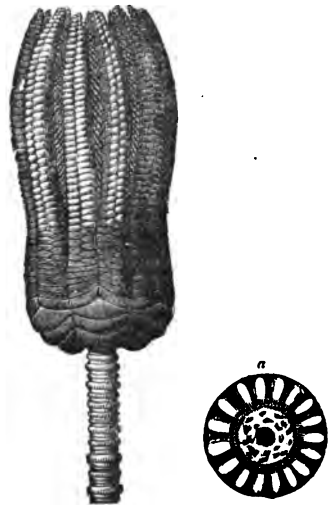
Characteristics of the Triassic Fauna and Flora.—In Britain and Central Europe generally, the marine fauna of the Trias is almost entirely unrepresented. The strata of that area appear to have been deposited for the most part in great salt-water lakes like the Caspian, and the Mollusca, when preserved, are few and often dwarfed. Even in the Muschelkalk, which contains great numbers of individuals, the variety of forms represented is not very great. It is necessary to go to the Alpine Trias of the South of Europe in order to form an idea of the rich and varied character of the marine fauna and to study the curious relations which it has with that of the Jurassic on the one hand, and that of the Permian and Carboniferous on the other hand.

Corals are very abundant in some of the strata of the Alpine Trias, and by some authors the formation of the great calcareous masses—which are now converted into dolomite, and form such conspicuous mountains in the Tyrol—is believed to be due to the action of reef-building corals of the period. The Echinoderms resemble those of the other Mesozoic rocks, the genus *Encrinus* being very well represented (fig. 419). Star-fish of Mesozoic types also occur (fig. 420). The Echini are of Mesozoic types, but are all regular forms; the irregular forms, so abundant in the Jurassic and Cretaceous, appear not to have made their appearance in Triassic times.

The Brachiopods are very abundant, but do not show in Triassic times that predominance over the Lamellibranchiata which is so distinctive of Palæozoic faunas. Some of the genera are related to those of the Palæozoic, others to those of the Mesozoic, while a few, like *Koninckia* (fig. 421), are confined to the Trias.

Among the very varied Lamellibranchiate fauna certain genera are very conspicuous, such as *Gervillia* (fig. 422), *Myophoria* (the precursors of the Jurassic and Cretaceous *Trigoniæ*), *Halobia*, *Daonella*, *Megalodon*, &c.

Fig. 419.

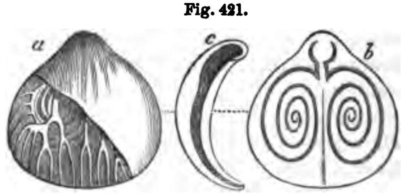


Encrinus liliiformis, Schloth., $\frac{2}{3}$.
Body, arms, and part of stem.
a. Section of stem. Muschelkalk.

Fig. 420.

Aspidura loricata, Ag.
a. Upper side. *b*. Lower side.
Muschelkalk.

Fig. 421.



Koninckia Leonhardi, Wissmann.

a. Ventral view. Part of ventral valve removed to show the vascular impressions of dorsal valve.
b. Interior of dorsal valve, showing spiral processes restored.
c. Vertical section of both valves. Part shaded black showing place occupied by the animal, and the dorsal valve following the curve of the ventral.

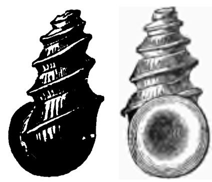
Gastropoda are very abundant in the Trias, and among them also we find an admixture of Palæozoic types, like *Murchisonia*, *Scoliostoma* (fig. 423), and *Loxonema*, with Jurassic forms, such

as *Cerithium*, *Emarginula*, &c. A few genera, like *Platystoma* (fig. 424), are peculiar to the Trias.

Fig. 422.

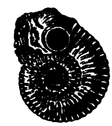
Gervillia (*Avicula*) *socialis*. Schloth., nat. size. Found in the Muschelkalk and Keuper.

Fig. 423.



Scoliostoma, St. Cassian.

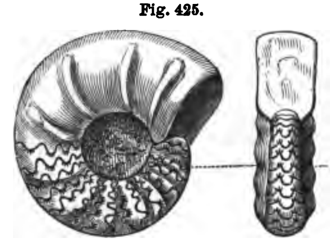
Fig. 424.



Platystoma Suessii, Hörnes. From Hallstadt.

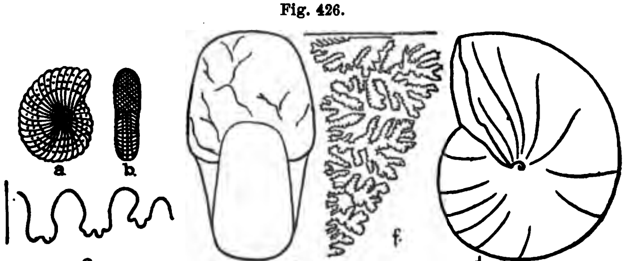
The Cephalopoda of the Trias are particularly interesting. The persistent genus *Nautilus* is well represented, and we find with it the last representatives of the Palæozoic Orthoceras. The most important representative of the Ammonoidea in the Trias is the characteristic *Ceratites* (fig. 425), but many remarkable genera of true Ammonites also occur. Among the Ammonites of the Trias some exhibit curiously foliated septa (see fig. 426, *d*, *e*, *f*),

Fig. 425.



Ceratites nodosus, Schloth., ½. Muschelkalk, Germany Side and front views, showing the peculiar forms of the septa dividing the chambers.

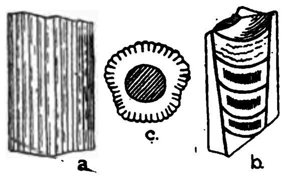
Fig. 426.



a, *b*, *c*. *Trachyceras Aon*, Münst. An Ammonite with very simply foliated sutures. *d*, *e*, *f*. *Arcestes multilobatus*, Brown. An Ammonite exhibiting sutures with very complicated foliations.

while others in the simplicity of the foliation of the sutures approach the *Ceratites* (see fig. 426, *a*, *b*, *c*). Many of the Ammonoidea are peculiar to the Trias, but others lived on into the Jurassic and Cretaceous. In *Atractites* and *Aulacoceras* (fig. 427) we have interesting forerunners of the great group of the Belemnites.

Fig. 427.



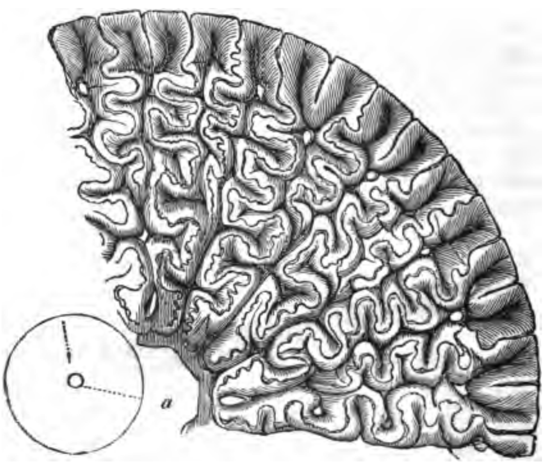
Aulacoceras sulcatum, ~~Hau., ½ nat.~~

a. Exterior of shell. *b*. Longitudinal section showing septa. *c*. Cross-section. The siphuncle, which is very thin, lies on the edge of the septa.

Fig. 428.

Tooth of *Labyrinthodon*; nat. size. Warwick sandstone.

Fig. 429.

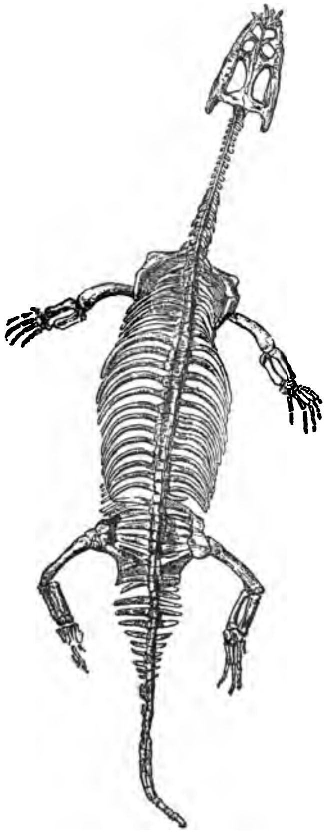


Transverse section of upper part of tooth of *Labyrinthodon Jaegeri*, Ow. (*Mastodonsaurus Jaegeri*, Meyer); natural size, and a segment magnified.
a. Pulp cavity, from which the processes of pulp and dentine radiate.

The Fish of the Trias include both Ganoids and Selachians. Among the former we find a great number with heterocercal tails like those of Palæozoic times mingled with others with homocercal tails like those of the Jurassic. The remarkable

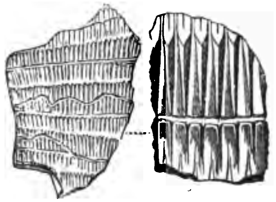
Dipnoid genus *Ceratodus*, which is still living in Queensland, is represented in the Trias; and we also find the first representatives of the Teleostei or bony fishes of our modern seas.

Fig. 430.



Lariosaurus Balsami, Curioni. Skeleton ⅛ nat. size. From the Muschelkalk, Lake Como, Italy.

Fig. 431.



Equisetum arenaceum, Schimp. Fragment of stem, and a small portion of same magnified. Keuper.

Fig. 432.

a. Voltzia heterophylla. Brong.
b. Portion of same magnified to show fructification. Sulzbad. Bunter-Sandstein.

Amphibians were very abundant in the Trias, and are referred to the group of the Stegocephala or Labyrinthodontia (figs. 428, 429).

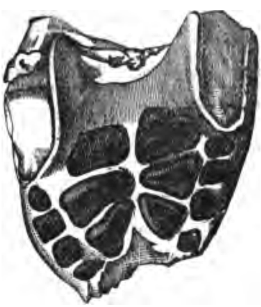
With these remarkable amphibians we find representatives of marine reptiles like *Lariosaurus* (fig. 430), which appear to

have been the précursors of the gigantic Enaliosauria (Ichthyosauria and Plesiosauria), so abundant in the Jurassic period.

The Terrestrial flora of the Trias consists of Conifers and Cycads, the former being represented by *Voltzia* (fig. 432), *Albertia*, &c., and the latter by *Pterophyllum*, *Zamites*, *Pseudozamites*, *Podozamites*, *Otozamites*, &c. Ferns are abundant, and a true *Equisetum* is also found (fig. 431).

Land Reptiles are represented by numerous forms in the Trias. Many of these belonged to the Rhynchocephalia. Crocodiles and Dinosaurs are found in the Trias, but no true Pterosauria, Lacertilia, Ophidians, or Chelonians. Many of the Reptilia of

Fig. 433.



Palatal teeth of *Placodus gigas*, Ag. Muschelkalk.

Fig. 434.

Tritylodon Fraasii, Lydekker. Upper true molar tooth. The two central figures of the natural size, the others enlarged (× 3).
o shows the triconodont character of the crown of the teeth; *u* the fangs; *v*, *h* lateral, *i* anterior, *a* posterior surfaces.
From the Upper Trias of Strasburg.

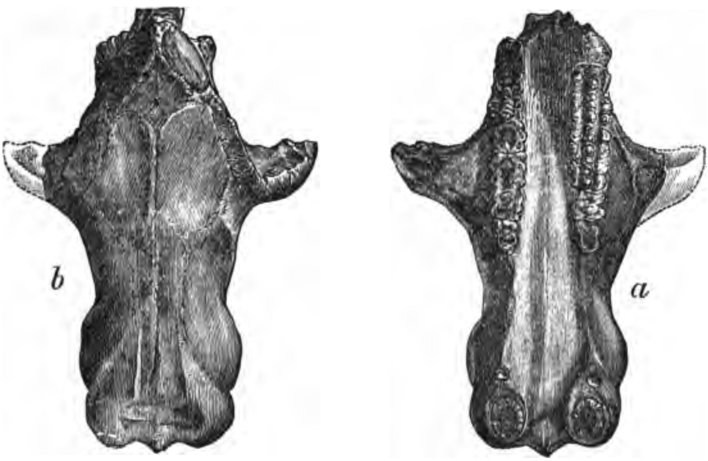
the Trias (Theriomorpha) curiously simulate the Mammalia in the forms of their skulls, the position of their eyes, the differentiation of their teeth, and other characters. To this remarkable group of Reptiles are referred not only the *Dicynodon* and many other forms with large teeth, like canines, but also the *Placodus*, with its flat palatal crushing teeth, which was formerly regarded as a fish.

Birds were unknown in the Trias, but mammals are represented by the *Tritylodon* (see fig. 435) from South Africa and some similar lowly forms (Prototheria or Allotheria), which have been found in the highest portion of the Trias and in the overlying Rhætic.

The remarkable 'triconodont' teeth which characterised these oldest known mammals are illustrated in fig. 434.

Professor Seeley regards *Tritylodon* as possibly being not a true mammal but a synthetic type intermediate between the

Fig. 435.



Tritylodon longævus, Owen. Skull with one side restored, ⅔ nat. size.
a. Palatal view of skull, showing molars and broken canines.
b. Upper surface of skull.
From the Trias of Basutoland, South Africa.

mammal-like reptiles (Theriodontia) and the lowest Mammalia (Allotheria).

British Representatives of the Triassic System.—The British Triassic strata consist of a succession of variegated sands and clays containing very few fossils, which it is often difficult to separate from the underlying Permian strata.

The Keuper.—This upper division is of great thickness in Lancashire and Cheshire, attaining 3,450 feet in the last-mentioned county, and it covers a large extent of country between Lancashire and Devonshire, but it thins out rapidly to less than half its thickness in Staffordshire.

Fig. 436.

Estheria minuta, Alberti sp.
Mag. 2 diams.

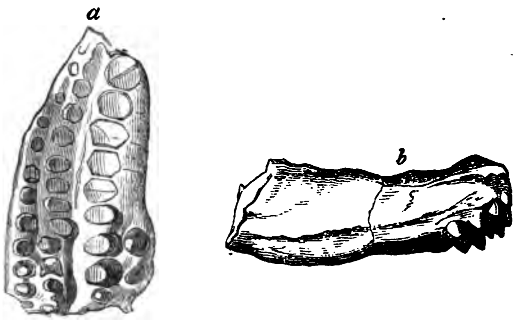
It consists of New Red Marl at the top, with red and grey shales and marls, rock-salt and gypsum being important minerals in it; and it rests on thinly laminated micaceous sandstones and waterstones, with a base of calcareous conglomerate or breccia.

In Worcestershire and Warwickshire, in sandstone belonging to the uppermost part of the Keuper, the bivalve crustacean *Estheria minuta*, Alberti sp., occurs. The member of the English 'New Red' containing this shell, in those parts of England, is, according to Sir Roderick Murchison and Mr. Strickland, 600 feet thick, and consists chiefly of red

marl or shale, with a band of sandstone. Spines of *Hybodus*, and teeth of other fishes, and footprints of reptiles were observed by the same geologists in these strata.

The remains of four saurians have been found. One called *Rhynchosaurus* occurred at Grinsell, near Shrewsbury, and is characterised by having a small bird-like skull and jaws without

Fig. 437.



Hyperodapedon Gordoni, Huxley. Left palate, maxillary.
(Showing the two rows of palatal teeth on opposite sides of the jaw.)
a. Under surface. *b.* Exterior right side.

teeth, but with a beak. The other three, *Telerpeton*, *Hyperodapedon* (fig. 437), and the crocodilian reptile *Stagonolepis*, were brought to light near Elgin, in strata formerly supposed to belong to the Old Red Sandstone, but now recognised as Upper Triassic. The *Hyperodapedon* was afterwards discovered in beds of about the same age, in the neighbourhood of Warwick, and also in South Devon, and remains of the same genus have been found in Central India and Southern Africa, in rocks believed to be of Triassic age.

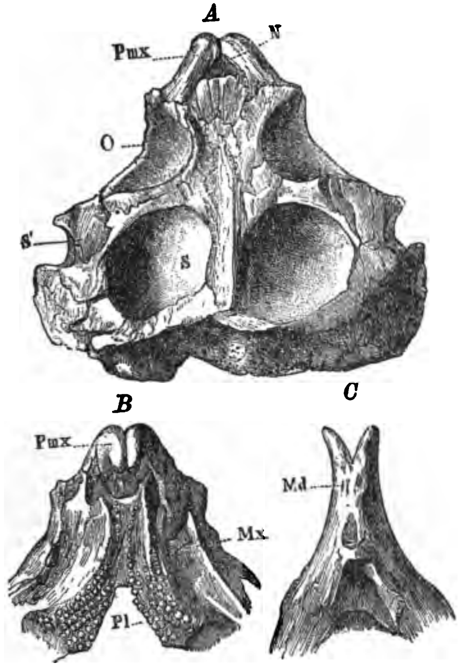
There has been discovered more recently, near Elgin, an almost complete skeleton of *Hyperodapedon*, which has been described by the late Professor Huxley, and the study of this remarkable specimen has brought out very clearly the points of resemblance of these Old Triassic reptiles to the living New Zealand lizard, *Sphenodon* (*Hatteria*), the sole survivor at the present day of the great order Rhynchocephalia, which is also represented in the Permian strata of Central Europe. The remarkable skull with beaks, and the dentition, of *Hyperodapedon* are represented on the opposite page.

The discovery of a living reptile in New Zealand so closely allied to this supposed extinct division of the Reptilia seems to afford an illustration of a principle pointed out by Mr. Darwin of the survival in insulated tracts, after many changes in physical geography, of orders, of which the congeners have become extinct on continents where they have been exposed to the severer competition of a larger and progressive fauna.

Still more recently, Mr. E. T. Newton has described some other forms of remarkable reptiles to which he has given the names of *Gordonia*, *Elginia*, &c. These are allied to the Dicynodontia and other Triassic reptiles of South Africa.

Dolomitic Conglomerate of Bristol.—Near Bristol, and on the flanks of the Mendips, in Somersetshire, and in other counties bordering the Severn, the lowest strata belonging to the Trias consist of a conglomerate or breccia, resting unconformably upon the Old Red Sandstone and on different members of the Carboniferous

Fig. 438.



Hyperodapedon Gordoni, Huxley. Skull and lower jaw (¼ nat. size). From Triassic Sandstone, Lossiemouth, near Elgin.

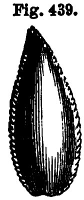
A. Upper surface of skull, showing O the orbits, S the supratemporal fossa, S' the lateral temporal fossa, N the anterior nares, and Pmx the pre-maxillary.
B. Palate, with teeth Pl and maxillary bones Mx.
C. Under side of front of lower jaw, with mandibles Md.

The peculiar dentition of the Rhynchosauria is well exhibited in this specimen, the rows of closely set conical palatal teeth acting against one another, as the jaw works backwards and forwards.

rocks, such as the Coal Measures, Millstone Grit, and Mountain Limestone. This mode of superposition will be understood by reference to the section of Dundry Hill (fig. 114, p. 134), where No. 4 is the dolomitic conglomerate. Such breccias may have been partly the result of the subaërial waste of an old land-surface which gradually sank down and suffered littoral denudation in proportion

as it became submerged. The pebbles and fragments of older rocks which constitute the conglomerate are cemented together by a red or yellow base of dolomite, and in some places the Encrinites, Corals, Brachiopoda, and other fossils derived from the Mountain Limestone are so detached from the parent rocks that they have the deceptive appearance of belonging to a fauna contemporaneous with the dolomitic beds in which they occur. Layers of Keuper are noticed between masses of the breccia. The embedded fragments are both rounded and angular, some consisting of Carboniferous limestone and Millstone-grit being of vast size, and many weighing nearly a ton. Fractured bones and teeth of saurians which are probably of contemporaneous age have been found in the lower part of the breccia, and two of these, called *Thecodontosaurus* (from the manner in which the teeth were implanted in the jawbone) and *Palæosaurus*, obtained great celebrity because the patches of red conglomerate in which they were found at Durdham Down, near Bristol, were originally supposed to be of Permian or Palæozoic age, and they were, therefore, considered the only representatives in England of vertebrate animals of so high a type in rocks of such antiquity. The teeth of *Thecodontosaurus* are conical, compressed, and with finely serrated edges (see fig. 438); both *Thecodontosaurus* and *Palæosaurus* were referred by Professor Huxley to the Dinosauria.

Fig. 439.



Tooth of *Thecodontosaurus*; 3 times magnified. After Riley and Stutchbury. Dolomitic conglomerate. Durdham Down, near Bristol.

The basement beds of the Keuper rest, with a slight unconformability, upon an eroded surface of the 'Bunter,' next to be described. In these basement beds Professor W. C. Williamson has described the footprints of a labyrinthodont which has been called '*Cheirotherium*' similar to those presently to be mentioned in the Bunter beds; this Keuper form, however, is peculiar in exhibiting a scaly surface.

Lower Trias, or Bunter.—The lower division or English representative of the 'Bunter' attains, according to Sir A. Ramsay, a thickness of 1,500 feet in the Midland counties. Besides red and green shales and red sandstones, it comprises much soft white quartzose sandstone, in which the trunks of silicified trees have been met with at Allesley Hill, near Coventry. Several of them were a foot and a half in diameter, and some yards in length, the wood being coniferous and showing rings of annual growth. Impressions, also, of the footsteps of animals have been detected in Lancashire and Cheshire in this formation. Some of the most remarkable occur a few miles from Liverpool, in the whitish quartzose sandstone of Storton Hill, on the Cheshire side of the Mersey. They bear a close resemblance to tracks first observed in this member of the Upper New Red Sandstone, at the village of Hesseberg, near Hildburghausen, in Saxony. For many years these footprints have been referred to a large unknown quadruped, provisionally named *Cheirotherium* by Professor Kaup, because the marks both of the fore and hind feet resembled impressions made by a human hand (see figs. 440, 441). The footmarks at Hesseberg are partly concave and partly in relief; the former, or the depressions, are seen upon the upper surface of the

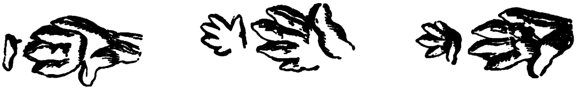
sandstone slabs, but those in relief are only upon the lower surfaces, being in fact natural casts, formed in the subjacent footprints as in moulds. The larger impressions, which seem to be those of the hind foot, are generally 8 inches in length and 5 in width, and one was 12 inches long. Near each large footstep, and at a regular distance (about an inch and a half) before it, a smaller print of a fore foot, 4 inches long and 3 inches wide, occurs. The footsteps follow each other in pairs, each pair in the same line, at intervals of 14 inches from pair to pair. The large as well as the small steps show the great toes alternately on the right and left side; each step makes the print of five toes, the first or great toe being bent inwards like a thumb. Though the fore and hind foot differ so much in size, they are nearly similar in form.

Fig. 440.

Single footstep of '*Cheirotherium*' Bunter-Sandstein, Saxony. One-eighth of natural size.

As neither in Germany nor in England had any bones or teeth been met with, in the same identical strata as the footsteps, anatomists indulged for several years in various conjectures respecting the mysterious animals from which they might have been derived.

Fig. 441.



Line of footsteps on slab of sandstone. Hildburghausen, in Saxony.

But M. Link conceived that some of the four species of animals of which the tracks have been found in Saxony might have been gigantic *Batrachians*; and when it was afterwards inferred that the Labyrinthodon was an Amphibian, it was suggested by Professor Owen that it might be one and the same as the *Cheirotherium*.

Origin of Red Sandstone and Rock Salt.—In Cheshire and Lancashire there are red clays of the age of the Trias containing gypsum and salt through a thickness of from 1,000 to 1,500 feet thick. In some places, lenticular masses of pure rock-salt nearly 100 feet thick are interpolated between the argillaceous beds. At the base of the formation beneath the rock-salt occur the Lower Sandstones and Marl, called provincially in Cheshire 'water-stones,' which are largely quarried for building. They are often ripple-marked, and are impressed with numerous footprints of reptiles.

As in various parts of the world red and mottled clays and sandstones, of several distinct geological epochs, are found associated with salt, gypsum, and magnesian limestone, or with one or all of these substances, there is, in all likelihood, a general cause for such a coincidence. Nevertheless, we must not forget that there are dense masses of red and variegated sandstones and clays, thousands of feet in thickness, and of vast horizontal extent, wholly devoid of saliferous or gypseous matter. There are also deposits of gypsum and of common salt, as in the blue clay formation of Sicily, without any

accompanying red sandstone or red clay.

These red deposits may possibly be accounted for by the decomposition of gneiss and mica schist, which in the Eastern Grampians of Scotland has produced a mass of detritus of precisely the same colour as the New Red Sandstone.

It is a general fact, and one not yet very satisfactorily accounted for, that scarcely any fossil remains are ever preserved in stratified rocks in which red oxide of iron abounds; and when we find fossils in the New or Old Red Sandstone in England, it is in the grey, and usually calcareous beds that they occur. Beds of rock-salt are generally attributed to the evaporation of lakes or lagoons communicating at intervals with the ocean. Sir A. Ramsay has remarked in regard to the Trias that it was probably a Continental Period with many inland lakes and seas, the Keuper marls of the British Isles having been deposited in a great lake, fresh or brackish, at the beginning, and afterwards rendered salt by evaporation. 'Were the rainfall,' he observed, 'of the area drained by the Jordan to increase gradually, the basin of the Dead Sea would by degrees fill with water, and successive deposits of sediment would gradually overlap each other on the shelving slopes of the lake basin in which solid salts had previously been deposited. There are examples of this kind of overlap in the New Red Marl of England, in Somerset, Gloucester, Hereford, and Leicester. Sir A. Ramsay suggests that the red peroxide of iron of the sands and clays may in itself be an indication of lacustrine conditions, for each grain of sand and mud is encrusted with a thin pellicle of peroxide of iron, which he thinks could not have taken place in a wide and deep sea.

Major Harris, in his 'Highlands of Ethiopia,' describes a salt lake called the Bahr Assal, near the Abyssinian frontier, which once formed the prolongation of the Gulf of Tadjara, but was afterwards cut off from the gulf by a broad bar of lava. 'Fed by no rivers, and exposed in a burning climate to the unmitigated rays of the sun, it has shrunk into an elliptical basin seven miles in its transverse axis, half filled with smooth water of the deepest cærulean hue, and half with a solid sheet of glittering snow-white salt, the offspring of evaporation.' 'If,' says Hugh Miller, 'we suppose, instead of a barrier of lava, that sand-bars were raised by the surf on a flat arenaceous coast during a slow and equable sinking of the surface, the waters of the outer gulf might occasionally topple over the bar, and supply fresh brine when the first stock had been exhausted by evaporation.'

The Runn of Cutch, as has been shown elsewhere, is a low region near the delta of the Indus, equal in extent to about a quarter of Ireland, which is neither land nor sea, being dry during part of every year, and covered by salt water during the monsoons. Here and there its surface is encrusted over with a layer of salt caused by the evaporation of sea-water. A subsiding movement has been witnessed in this country during earthquakes, so that a great thickness of pure salt might result from a continuation of such sinking.

For further information on the Triassic rocks of this country, the student may consult the Geological Survey Memoir on 'The Triassic and Permian Rocks of the Midland Counties of England,' by E. Hull. The Elgin Sandstone and its fossils have been discussed in memoirs by Murchison, Harkness, Lyell, Huxley, Judd, and E. T. Newton.

CHAPTER XIX

FOREIGN DEPOSITS WHICH ARE HOMOTAXIAL WITH THE MESOZOIC STRATA OF THE BRITISH ISLES

Secondary Strata of Central Europe—Keuper, Muschelkalk, and Bunter—The Black, Brown, and White Jura—Planer and Quader Beds—Chalk of Maestricht and Faxoe—Freshwater Strata—Wealden of Hanover—Strata of Aix-la-Chapelle—Secondary Strata of the Alpine Regions—Hallstadt and St. Cassian Beds—Alpine Jurassic, Tithonian, and Neocomian—Hippurite Limestones—Secondary Strata of Russia, India, and South Africa—Secondary Strata of North America—Newark Formation—Strata of the Eastern States and of the Western Territories.

It is a remarkable fact that, although the base of the Triassic rocks in Europe is not always readily separable from the Palæozoic formation beneath, there is a vast palæontological break between them.

The Mesozoic age commenced when the first deposits of the Trias accumulated, and many hundreds of species common in the lower rocks ceased to exist, whilst a great marine fauna soon prevailed of an almost totally different kind from that which previously existed. The plants of the Mesozoic age were foreshadowed in the Palæozoic, and some genera persisted into the Trias, but the majority ceased to exist. Some of the lower forms of invertebrate life persisted through the great change in the physical geography of the world which commenced at the close of the Carboniferous age. Of the corals, not a genus or species lived on, and many new genera are found in the marine Trias. *Nautilus* and *Orthoceras* lived on as genera, and *Ammonites*, which commenced in Permian times, attained an enormous development. A great change occurred in the Mollusca and Crustacea. The Labyrinthodontia persisted, and many genera of Ganoid fish. But the number of genera of all kinds, animals and plants, which passed from the Palæozoic to the Mesozoic was small.

The marine faunas of the Mesozoic era attained their fullest development in Jurassic times, and during the Cretaceous periods begin to show signs of decadence, and of their replacement by the forms of life so characteristic of the Cainozoic.

The terrestrial flora which characterises the Mesozoic rocks had, however, to a great extent been replaced by the Cainozoic flora long before the end of the Cretaceous Period.

The oldest of the three great Mesozoic systems is much better represented on the Continent of Europe than it is in this country. In the Alps we have at St. Cassian in the south, and at Hallstadt on the north, thick masses of marine strata crowded with abundant and well-preserved fossils.

MESOZOIC STRATA OF CENTRAL EUROPE

Trias of Germany.—In Germany, as before noticed, the Trias first received its name as a Triple Group, consisting of two sandstones with an intermediate marine calcareous formation, which last is wanting in England.

The succession of strata in the great German Triassic basin is—Upper Trias or Keuper, with red marls, plant-beds, gypsum, and rock-salt, overlying the Letten Kohle, with *Voltzia*, *Estheria minuta*, Alb., the Labyrinthodont *Mastodontosaurus*, and the fish *Ceratodus*. Then comes the Muschelkalk, with limestones, containing *Myophoria*, *Ceratites*, and *Encrinus liliiformis*, Lam., followed by Bunter—red and green marls and coarse sandstones—with *Voltzia*, *Estheria*, and *Myophoria*.

The plants of the Trias belong partly to Coniferæ, the genus *Voltzia*, with its cypress-like twigs, being characteristic. The genus *Albertia* is also represented. Ferns were numerous: genera, *Pecopteris*, *Cyclopteris*, *Anomopteris*, *Acrostichites*, *Clathropteris*, *Sagenopteris*, *Tæniopteris*, &c. Cycads, *Pterophyllum*, *Zamites*, *Pseudozamites*, *Podozamites*, and *Otozamites*. These last prevailed extensively, and have given the term 'Age of Cycads' to the Trias. A true *Equisetum* exists, and an ally, the genus *Schizoneura*.

Keuper of Germany.—The sandstones of the Keuper of Germany, like those of England and France, contain the remains of plants, reptilia, and very few marine organisms.

Muschelkalk. — This consists chiefly of a compact greyish limestone, but includes beds of dolomite in many places, together with gypsum and rock-salt and clays. This limestone—a formation wholly unrepresented in England — abounds in fossil shells, as the name implies. Among the Cephalopoda there are no *Belemnites*, and no *Ammonites* with completely foliated sutures, as in the Lias and Oolite and the Hallstadt beds; but the genus *Ceratites* is present, in which the lobes of the sutures seen on the shell are denticulated or crenulated, whilst the 'saddles' are simply rounded. Among the bivalve crustacea, the *Estheria minuta*, Alb. (fig. 436), is abundant, ranging through the Keuper and Muschelkalk; and *Gervillia socialis* (fig. 422), having a similar range, is found in great numbers in the Muschelkalk of Germany, France, and Poland.

The abundance of the heads and stems of lily encrinites, *Encrinus liliiformis*, Schloth. (fig. 419), shows the slow manner in which some beds of this limestone have been formed in clear sea water. The star-fish called *Aspidura loricata*, Ag. (fig. 420), is as yet peculiar to the Muschelkalk. In the same formation are found the skull and teeth of the genus *Placodus* (see fig. 433). Perfect specimens enabled Professor Owen, in 1858, to show that this fossil was a Saurian, which probably fed on shell-bearing molluscs, and used its short and flat teeth, so thickly coated with enamel, for pounding and crushing the shells.

Bunter - Sandstein. — The Bunter-Sandstein consists of various-coloured sandstones, dolomites, and red clays, with some beds, especially in the Hartz, of calcareous pisolite or roe-stone, the

whole sometimes attaining a thickness of more than 1,000 feet. The sandstone of the Vosges is proved, by its fossils, to belong to this lowest member of the Triassic group. At Sulzbad (or Saultz-les-Bains), near Strasburg, on the flanks of the Vosges, many plants have been obtained from the 'Bunter,' especially conifers of the extinct genus *Voltzia*, of which the fructification has been preserved. (See fig. 482.) Out of thirty species of ferns, cycads, conifers, and other plants, enumerated by M. Ad. Brongniart, in 1849, as coming from the 'Grès bigarré,' or Bunter, not one is common to the Keuper.

The footprints of *Labyrinthodon* observed in the clays of this formation at Hildburghausen, in Saxony, have already been mentioned. Some idea of the variety and importance of the terrestrial vertebrate fauna of the three members of the Trias in Northern Germany may be derived from the fact that in the great monograph by the late Hermann von Meyer on the reptiles of the Trias, the remains of no less than eighty distinct species are described and figured.

Jurassic strata of Central Europe.—These have been studied with great care, especially by Marcou in the Jura, and by Quenstedt and Oppel in Suabia. While the general parallelism of these strata with those made out by William Smith in England is very striking, the local differences are of unmistakable character. A very great number of palæontological horizons, each characterised by a species of Ammonite or other fossil, have been defined under the name of zones; and, over all the districts referred to, these zones may be traced more or less continuously, though some horizons are represented by thick masses of sediments, while others appear only as thin and insignificant bands, and some are, over considerable areas altogether absent.

Throughout Central Europe the succession of Jurassic strata represented in this country can be clearly followed, although the mineral characters of some of the horizons differ very widely from the British representatives. This succession of zones, with the group-names applied to them, is given in the following table:—

Portlandian	Zone of	*Trigonia gibbosa*, Sow.	
Kimeridgian	,,	*Discina latissima*, Sow.	
	,,	*Exogyra virgula*, Defr.	
	,,	*Ammonites alternans*, V. Buch.	
	,,	*Astarte supracorallina*, D'Orb.	
	,,	*Ostrea deltoidea*, Sow.	
Corallian	,,	*Ammonites*	(*Perisphinctes*) *plicatilis*, Sow.
	,,	,,	(*Aspidoceras*) *perarmatus*, Sow.
Oxfordian	,,	,,	(*Cardioceras*) *cordatus*, Sow.
	,,	,,	(*Cosmoceras*) *ornatus*, Schloth.
Callovian	,,	,,	(*Stephanoceras*) *macrocephalus*, Schloth.
Bathonian	,,	,,	(*Oppelia*) *asphidioides*, Opp.
	,,	,,	(*Parkinsonia*) *ferrugineus*, Opp.
Bajocian	,,	,,	(*Parkinsonia*) *Parkinsoni*, Sow.
	,,	,,	(*Stephanoceras*) *Humphresianus*, Sow.
	,,	,,	(*Stephanoceras*) *Sauzei*, D'Orb.
	,,	,,	(*Hammatoceras*) *Sowerbyi*, Mill.
	,,	,,	(*Ludwigia*) *Murchisoniæ*, Sow.
	,,	,,	(*Ludwigia*) *opalinus*, Rein.

Toarcian	Zone of *Ammonites*	(*Lytoceras*) *jurensis*, Ziet.
	„ „	(*Hildoceras*) *bifrons*, Brug.
	„ „	(*Harpoceras*) *serpentinus*, Rein.
Liasian (Charmouthian)	„ „	(*Amaltheus*) *spinatus*, Brug.
	„ „	(*Amaltheus*) *margaritatus*, De Montf.
	„ „	(*Ægoceras*) *capricornis*, Schloth.
	„ „	(*Amaltheus*) *ibex*, Quenst.
	„ „	(*Ægoceras*) *Jamesoni*, Sow.
Sinemurian	„ „	(*Arietites*) *raricostatus*, Ziet.
	„ „	(*Oxynotieras*) *oxynotus*, Quenst.
	„ „	(*Arietites*) *obtusus*, Sow.
	„ „	(*Arietites*) *semicostatus*, Y. & B.
	„ „	(*Arietites*) *Bucklandi*, Sow.
Hettangian	„ „	(*Schlotheimia*) *angulatus*, Schloth.
	„ „	(*Ægoceras*) *planorbis*, Sow.

In some cases geologists and palæontologists have found it necessary to establish still smaller subdivisions than these zones in describing the succession of the Jurassic strata. Such minor subdivisions have been called by Mr. S. Buckman 'hemare.'

In France and Germany the succession of strata representing these life-zones has been studied in great detail, and the parallelism of the different horizons throughout Western Europe is sufficiently obvious. There are many interesting local variations in the sequence of beds, in the degree of representation of different horizons, and even in the fossils which characterise the different zones, which are worthy of the closest attention as indicating the varying conditions under which the strata of this age were accumulated. In Germany the Lias is usually called the 'Black Jura,' the Lower Oolites 'Dogger, or Brown Jura,' and the Middle and Upper Oolites the 'Malm,' or 'White Jura.'

Shallow-water Representatives of the Chalk.—Chalk strata are found all through Central Europe and passing into Asia. In the south of Russia the Upper Cretaceous is represented by beds of chalk, which have been proved by deep borings to be nearly 2,000 feet in thickness.

Although the great mass of the chalk was evidently deposited in moderately deep water, we can in places trace the shores of the sea in which the beds were formed. Thus in the north-east of Ireland beds of conglomerate containing chalk fossils are seen resting on the old metamorphic rocks of the district; and in Bohemia and Saxony the calcareous beds of the chalk are found passing into masses of sandstone (Quader Sandstone) and into marls (Planer Marls), evidently formed under littoral conditions. At some points, as at Aix-la-Chapelle, the Western Isles of Scotland, and the east coast of Greenland, beds of freshwater origin are found intercalated with the Upper Cretaceous marine beds, and these freshwater beds have yielded a very interesting series of plant-remains.

Freshwater Strata of Cretaceous Age of Central Europe.—The Wealden or freshwater representatives of the Lower Cretaceous are found extending into the north of France; and strata of about the same age occur in Hanover. Freshwater beds containing a terrestrial fauna have been studied at Aix-la-Chapelle. These strata are of the same age as our Upper Chalk; they consist of white sands and laminated clays, and attain a thickness of 400 feet. With the exception of a few bands containing marine shells, all these strata are of freshwater

origin, and they contain a series of plant-remains which deserve particular attention. Nearly 100 species are recorded by Debey in the lists of the 'Géologie de la Belgique' (M. Mourlon, 1881). Of fourteen genera of ferns, three are still existing—namely, *Gleichenia*, now inhabiting the Cape of Good Hope and New Holland; *Lygodium*, now spread extensively through tropical regions, but having some species which live in Japan and North America; and *Asplenium*, a living cosmopolite form. The genus *Pteridoleimma* is represented by no less than 22 species, or nearly one-half of the whole flora of ferns.

Among the phanerogamous plants, the Conifers are abundant, the most common belonging to the genus *Sequoia* (or Wellingtonia), of which both the cones and branches are preserved. The silicified wood of this plant is very plentifully dispersed through the white sands in the pits near Aix. In one silicified trunk 200 rings of annual growth have been counted. The Monocotyledons there are very peculiar types. No Palms have been recognised with certainty, but a species of *Pandanus*, or Screw-pine, is found. But the number of the Dicotyledonous Angiosperms is the most striking feature in this ancient flora.

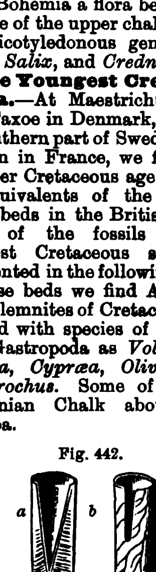
Among them we find five species of the Oak (*Dryophyllum*), a genus very American in its affinities.

The resemblance of the flora of Aix-la-Chapelle to the tertiary and living floras is considerable, but the angiospermous Dicotyledons did not commence with the Tertiary age, but long before. We can now affirm that these Aix plants flourished before the rich reptilian fauna of the secondary rocks had ceased to exist. The *Ichthyosaurus*, *Pterodactylus*, and *Mosasaurus* were of coeval date with the plant *Dryophyllum*. Speculations have often been hazarded respecting a connection between the rarity of Exogens in the older rocks and a peculiar state of the atmosphere. A denser air, it was suggested, had in earlier times been alike adverse to the well-being of the higher order of flowering plants, and of the quick-breathing animals, such as mammalia and birds, while it was favourable to a cryptogamic and gymnospermous flora, and to a predominance of reptile life. But we now learn that there is no incompatibility in the co-existence of a vegetation like that of the present globe, and some of the most remarkable forms of the extinct reptiles of the age of gymnosperms.

In Bohemia a flora belonging to the base of the upper chalk contains the Dicotyledonous genera *Acer*, *Alnus*, *Salix*, and *Credneria*.

The Youngest Cretaceous Strata.—At Maestricht in Holland, Faxoe in Denmark, in Scania, the southern part of Sweden, and at Meudon in France, we find strata of Upper Cretaceous age overlying the equivalents of the youngest Chalk beds in the British Islands. Some of the fossils of these youngest Cretaceous strata are represented in the following figures. In these beds we find Ammonites and Belemnites of Cretaceous types mingled with species of such Tertiary Gastropoda as *Voluta*, *Fasciolaria*, *Cypræa*, *Oliva*, *Mitra*, and *Trochus*. Some of the beds of Danian Chalk abound with Bryozoa.

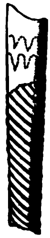
Fig. 442.



Belemnitella mucronata, Schloth., ½.
Maestricht, Faxoe, and White Chalk.

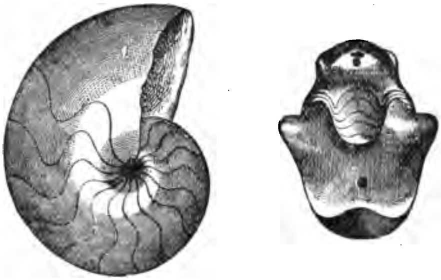
b. Osselet or guard, showing vascular impressions on outer surface, with characteristic slit, and mucro.
a. Section of same, showing place of phragmacone.

Fig. 443.



Portion of *Baculites Faujasii*, Sow.
Maestricht and Faxoe beds and White Chalk.

Fig. 444.



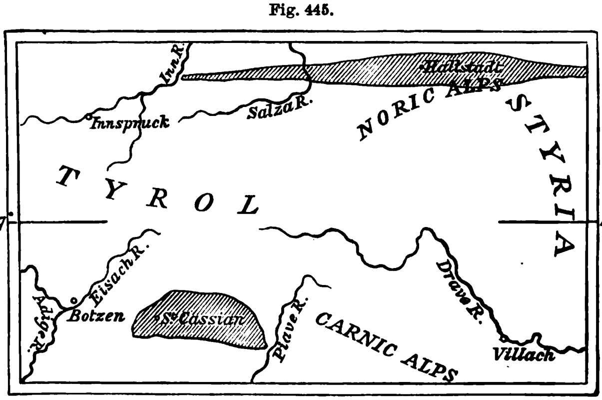
Nautilus danicus, Schloth. Faxoe, Denmark. Maestricht, &c.

MESOZOIC STRATA OF THE ALPS AND SOUTHERN EUROPE

The Alpine Trias. — The richness of the fauna of the Alpine Trias has been already referred to. Mojsisovics has shown that the strata on the south of the Alps (St. Cassian, &c.) belong to a different life-province from that in which those on the north side of the same chain (Hallstadt beds) were deposited. These life-provinces he has named the Mediterranean and Juvavian provinces respectively; and he has shown that each is distinguished by assemblages of peculiar Ammonites and other shells.

Triassic strata, closely related to those of the Alps, are found extending through Southern Europe and Asia into the Indian peninsula, and through Siberia into Japan. Strata with similar fossils reappear in the western territories of the United States, in Alaska and British Columbia.

Fig. 445.



Map showing the position of St. Cassian and Hallstadt areas.

The Trias is grandly developed in the Eastern Alps. Including the Rhætic beds, which link the Trias and the Lias, the following is the succession of the great groups of strata.

The Rhætic group, consisting of marine limestones, dolomites, and (rarely) shales: 1. Kössen beds and Azarolla beds, with corals, Brachiopoda, and Lamellibranchiata, such as *Gervillia*. 2. Dachstein limestone, with large forms of *Megalodon* or the Dachstein bivalve, numerous corals, and Brachiopoda. 3. Dolomites. A pale, well-bedded, finely crystalline rock, usually without fossils.

Upper Trias: 1. Cardita beds and Raibl beds, shales, marls with plants, Crustacea, Cephalopoda, and fish. 2. Hallstadt limestone and Esino beds, red and mottled marbles and limestones, with many Cephalopoda and large Gastropoda. The Schlern Dolomite, 3,820 feet thick, forming picturesque mountains. 3. Lunz beds, containing coal with plants, and forming the only freshwater group. 4. Zlambach coral beds. 5. St. Cassian beds—calareous marls of South Tyrol, with *Ammonites*, Gastropoda, Lamellibranchiata, Brachiopoda, Crinoidea, Echinoidea, and Corals. 6. *Halobia-Lommelii* beds. Then comes the Lower Trias. 7. Alpine Muschelkalk, limestones, and dolomites, with lower strata containing *Ceratites*, which are equivalent to the Upper Division of the Bunter.

Other Alpine deposits of marine origin occur in Southern Europe, of which the great masses of limestone of Hallstadt, north of the Alps, are the type. Huge *Ammonites* characterise these deposits. On the south of the Tyrol the St. Cassian beds were forming a little earlier, and the fauna was rich in the extreme. The following are characteristic genera—*Scoliostoma* (fig. 423), *Platystoma* (fig. 424), and *Koninckia* (fig. 421).

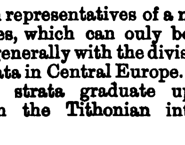
Ammonites and *Orthoceratites* occur in the St. Cassian and Hallstadt beds. As the Orthocerata, which are common in some palæozoic rocks, had never been met with in the Muschelkalk of the Lower Trias, much surprise was felt that seven or eight species of the genus should appear in the Hallstadt beds of the Upper Trias. Some are of large dimensions, and are associated with large *Ammonites* with foliated lobes, a form never seen before so low in the Mesozoic series. *Cerithium*, so abundant in tertiary strata, and which still exists, is represented by no less than fourteen species.

A rich fauna, comprising 225 species, of which about one-fourth are identical with those of St. Cassian, has been brought to light at D'Esino, in Lombardy, and has been admirably illustrated by Professor Stoppani. He described 65 species of the genus of spiral univalve *Chemnitzia*, reminding us by its abundance of the Cerithia of the Paris basin, while the enormous size of some specimens would almost bear comparison with the *Ceritheum giganteum*, Lam., of that Eocene formation.

The study of the rich marine fauna of Hallstadt and St. Cassian of the Upper Trias or Keuper convinces us that when the strata of the Triassic age are better known, especially those belonging to the period of the Bunter Sandstone, the break between the Palæozoic and Mesozoic Periods will to a great extent disappear.

Jurassic strata of the Alps.—In the Alpine region the thick limestones of Jurassic age

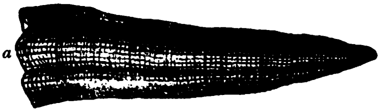
Fig. 446.



Terebratula (*Pygope*) *diphya*, Col.

contain representatives of a number of zones, which can only be compared generally with the divisions of the strata in Central Europe. These Alpine strata graduate upwards through the Tithonian into the

Fig. 447.



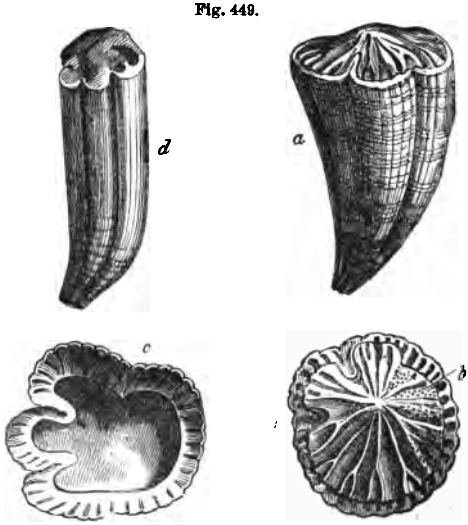
a. Radiolites radiosa, D'Orb.
b. Upper valve of same.

White Chalk of France.

Fig. 448.

Radiolites foliaceus, D'Orb.
Syn. *Sphærulites agariciformis*, Blainv.
White Chalk of France.

Fig. 449.



Hippurites organisans, Desmoulins.
Upper Chalk : Chalk marl of Pyrenees.

a. Young individual; when full grown they occur in groups adhering laterally to each other.
b. Upper side of the upper valve, showing a reticulated structure in those parts, *b*, where the external coating is worn off.
c. Upper end or opening of the lower and cylindrical valve.
d. Cast of the interior of the lower conical valve.

Neocomian, and downwards through the Rhætic (or Dachstein and Kössen beds) into the Trias. The Tithonian are a remarkable series of strata containing many peculiar forms of Cephalopoda and other shells, among the most characteristic of which are the singular diphyoid Terebratulæ (*Pygope*), fig. 446. By many authors the Tithonian strata are classed as Upper Jurassic.

The Cretaceous strata of Southern Europe.—The general succession of Cretaceous strata in Western Europe, as we have seen,

closely resembles that of our own country, but in Southern France and Switzerland the Lower Cretaceous or Neocomian becomes greatly developed, containing a wonderfully rich and varied fauna, and being divisible into a number of distinct zones.

The Neocomian strata of the Alps are several thousands of feet in thickness and have a very rich fauna, including many remarkable forms of Ammonites and Belemnites. They graduate downwards into that other thick series of limestones referred to, the Tithonian, a great system of strata not represented by marine beds in the British Islands, which appears to bridge over the interval between the Cretaceous and the Jurassic Periods.

In the south of France and the Alpine districts of Southern Europe the Upper Cretaceous is represented by thick masses of calcareous and other strata. These contain a fauna differing in many respects from the fauna of the Cretaceous of Central Europe. Many of the beds of limestone of Upper Cretaceous age (Hippurite limestones) are almost entirely made up of the shells of the large and remarkable bivalves belonging to the extinct group of the Rudistes. Some of the chief forms of these Rudistes are shown in the figures on the opposite page.

MESOZOIC STRATA OF OTHER PARTS OF THE EASTERN HEMISPHERE

Trias of India and South Africa.—There is a marine Trias in the Himalaya and in Baluchistan with Muschelkalk and St. Cassian species of somewhat different types from those of Europe. But the great development is in the peninsula, where the terrestrial remains of the period form vast coal-beds and shales and clays with plants and animals belonging to the same periods. In Australia, in New South Wales, Victoria, and Queensland are important coal-bearing strata.

Below these Triassic (Pánchet) beds are still thicker series of coal-bearing strata which are referred to the Permo-Carboniferous and even older periods (Rániganj and Talchir Series).

In South Africa extensive beds (the Karoo beds) containing similar plant remains and many remarkable forms of terrestrial reptiles, which have been made known to us by the labours of Professors Owen and Seeley, cover an enormous area and attain a great thickness.

The Triassic rocks of Southern Europe and Asia have been shown by the labours of Neumayr and Mojsisovics to have been accumulated in two life-provinces, to which the last-named geologist gave the names of the Juvavian province (lying north of the present Alps) and the Mediterranean province (lying south of that chain). In each of these provinces shallow-water and deep-water facies have been distinguished, and the effects of climate in influencing the distribution of life-form can be distinctly traced.

In Siberia, Spitzbergen, and Japan, and the western portions of the North American continent, Triassic strata cover wide areas. In spite of the presence of many characteristic genera of Triassic Cephalopods, Mojsisovics points out that there are many remarkable differences between the fauna of these Asiatic strata and those of Europe, and he regards them as constituting another life-province, the 'Arcto-Pacific.'

Jurassic strata of Russia and the Arctic Regions.—In Russia, and in the northern parts of Europe, Asia, and North America, we find very widely distributed a series of strata possessing a number of features in common with the Upper and Middle Oolites, but at the same time offering many very striking differences from the typical Jurassic. The same formations, characterised by the peculiar genus *Aucella*, by the presence of many

distinctive types of Ammonites and Belemnites, as well as by the absence of many forms found in the typical Jurassic, also extends southwards into the western territories of the United States. It is a remarkable circumstance that not a few Ammonites and other fossils of Jurassic types are found as far north as the east coast of Greenland, and in the adjoining islands of the Arctic Ocean.

Cretaceous Strata of Greenland, &c.—A Cretaceous flora has been discovered in Greenland of Cénomanian age at 70° N.L., and its genera resemble those of the Dakota group (p. 335) of the Cretaceous Formation of the Western Territories of the United States. There are Ferns, and a great assemblage of Dicotyledons, including many evergreens and conifers.

A second flora, which is probably of Lower Cretaceous age, is remarkable for having only yielded one Dicotyledonous (Angiospermous) species, but numerous *Conifers*, many *Cycads*, and a few *Monocotyledons*. (See p. 335.)

MESOZOIC STRATA OF NORTH AMERICA

The Newark System of the Eastern States.—While in the Old World it appears to be generally possible to divide the Mesozoic strata into the three great systems Triassic, Jurassic, and Cretaceous, such is certainly not the case in the New World.

When we cross the Atlantic, we find in the Eastern States of North America a series of strata (the Newark system) upwards of 4,000 feet in thickness, which are clearly homotaxial with the Jurassic and Triassic taken together, but in which it is impossible to establish any exact parallelism with the several divisions of those systems. They consist of reddish sandstones and shales, with a few thin beds of limestone and coal.

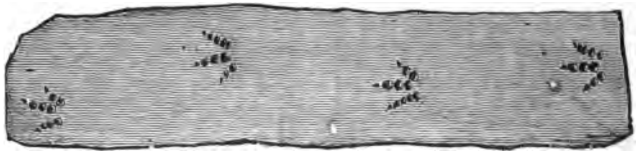
In the Eastern United States, the Triassic, Rhætic, and part of the Jurassic system appear to be represented by this 'Newark System,' which, in great part at least, seems to have been of freshwater origin. Near Richmond, in Virginia, beds of coal made up of the remains of Cycads and *Equisetum* occur. With the plant remains are found many Crustaceans, including forms of *Estheria*, similar to those so abundant in the European Trias, and many Ganoid fish.

In the Connecticut Valley strata of red sandstone occur which often exhibit great numbers of tracks formerly regarded as those of birds, but now believed to have been made by Labyrinthodonts and Dinosaurs.

The footprints of, it is supposed, no less than 50 species of animals have been detected in these rocks. The tracks have been found in more than twenty places scattered through an extent of nearly 80 miles from north to south, and they are repeated through a succession of beds attaining at some points a thickness of more than 1,000 feet. Yet no traces of bones or teeth have ever been detected in the beds.

In North Carolina the teeth of a small mammal (*Dromatherium*)

Fig. 450.



Footprints of a Dinosaur (?). Turner's Falls, Valley of the Connecticut.

have been found in the same strata. It is closely related to the European *Microlestes*.

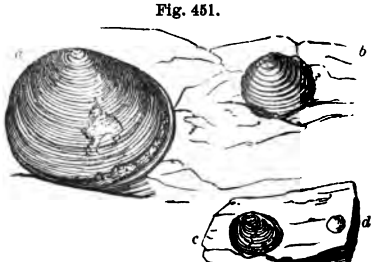
The formation covers an immense area, and may be divided into the Eastern and Western series. The former are freshwater and terrestrial accumulations, and the latter are marine deposits. In the eastern area the valley of the Connecticut river offers a type. In a depression of the granitic or hypogene rocks in the States of Massachusetts and Connecticut, strata of red sandstone, shale, and conglomerate are found, occupying an area more than 150 miles in length from north to south, and about 5 to 10 miles in breadth, the beds dipping to the eastwards at angles varying from 5 to 50 degrees. Having examined this series of rocks in many places, Lyell concluded that they were formed in shallow water, and for the most part near the shore, and that some of the beds were from time to time raised above the level of the water, and laid dry, while a newer series composed of similar sediment was forming.

The age of the Connecticut beds cannot be proved by direct superposition, but may be presumed from the general structure of the country. That structure shows them to be newer than the movements to which the Appalachian or Alleghany chain owes its flexures, and this chain includes the ancient or palæozoic Coal-formation among its contorted rocks.

Coal-field of Richmond, Virginia.—In the State of Virginia, at the distance of about 13 miles eastward of Richmond, the capital of that State, there is a Coal-field, occurring in a depression of the granite rocks and occupying a geological position analogous to that of the New Red Sandstones, above mentioned, of the Connecticut Valley. It extends 26 miles from north to south, and from 4 to 12 from east to west.

The plants consist chiefly of *Zamites*, *Equisetaceæ*, and ferns, and were considered by Heer to have the nearest affinity to those of the European Keuper.

Fig. 451.



a. *Estheria ovata*. Lea sp. *b*. Young of same.
c. Natural size of *a*. *d*. Natural size of *b*.
Triassic coal-shale, Richmond, Virginia.

The horsetails are very commonly met with in a vertical position, more or less compressed. It is clear that they grow in the places where they are now found, and were buried in strata of hardened sand and mud. They maintain their erect attitude, at points many miles apart, in beds both above and between the seams of coal. In order to explain this fact we must suppose such shales and sandstones to have been gradually accumulated during the slow and repeated subsidence of the whole region.

The fossil fish are Ganoids, some of them of the genus *Catopterus*, others belonging to the Liassic genus *Tetragonolepsis* (*Æchmodus*) (see fig. 325, p. 278). Amongst the

Crustacea, two or more species of Entomostraca called *Estheria* are in such profusion, in some shaly beds, as to divide them like the plates of mica in micaceous shales. (See fig. 450.)

These Virginian Coal-measures are composed of grits, sandstones, and shales, closely resembling those of palæozoic date in America and Europe; and the measures rival those of the last-named continent in the thickness of the coal-seams. One of these, the main seam, is in some places from 30 to 40 feet thick, and is composed of bituminous coal.

The *Dromatherium*, before alluded to, is at least as ancient as the Microlestes of the European Rhætic, described p. 308; and the fact is highly important, as proving that a certain low grade of marsupials had not only a wide range in time, from the Trias to the Purbeck of Europe, but had also a wide range in space, namely, from Europe to North America, in an east and west direction, and, in regard to latitude, from Stonesfield, in 52° N., to North Carolina, in 35° N. A somewhat similar mammal (*Tritylodon*), has been found in the Triassic beds of South Africa, and others also in the Cretaceous of the United States.

If the three localities in Europe where the most ancient mammalia have been found—Purbeck, Stonesfield, and Stuttgart—had belonged all of them to formations of the same age, we might well imagine so limited an area to have been peopled exclusively with pouched quadrupeds, just as Australia[1] now is, while other parts of the globe were inhabited by placental, or ordinary Mammalia. But the great difference of age of the strata in each of these three localities seems to indicate the predominance throughout a vast lapse of time (from the era of the Upper Trias to that of the Purbeck beds) of a low grade of Mammalia; and there must also have been a vast extension in geographical area of the marsupials during that portion of the Secondary or Mesozoic era which has been called the Age of Reptiles. The predominance of these Mammalia of a low grade during the whole of the Mesozoic, and the absence of the higher forms of Mammalia, are strongly suggestive of a progressive development of life-forms. It is also a very significant circumstance, which has been pointed out by Professor Seeley and others, that the Triassic reptiles of South Africa exhibit, in the differentiation of their teeth and many other peculiarities of their structure, very curious affinities with the mammals.

While the Jurassic strata are very imperfectly exhibited in North America, being only recognisable as possibly represented in the Newark formation, the Cretaceans are certainly present in the same area, but exhibit many striking differences from their European equivalents.

We find in the State of New Jersey a series of sandy and argillaceous beds wholly unlike in mineral character to our Upper Cretaceous system of Europe; which we can, nevertheless, recognise as referable, palæontologically, to the same division.

That they were about the same age generally as the European Chalk and Neocomian was the conclusion to which Dr. Morton and Mr. Conrad came after their investigation of the fossils in 1834. The strata consist chiefly of greensand and green marl, with an overlying coral limestone of a pale yellow colour, and the fossils, on the whole, agree most nearly with those of the Upper European series, from the Maestricht beds to the Gault inclusive. Among sixty shells from the New Jersey deposits, five were found as early as

[1] Australia now supports one hundred and sixty species of marsupials, while the rest of the continents and islands are tenanted by about seventeen hundred species of Mammalia, of which only forty-six are marsupial, and these are of a different family from the marsupials of Australia—namely, the opossums of North and South America.

1841 to be identical with European species—*Ostrea larva*, Lam., *O. vesicularis*, Lam., *Gryphæa costata*, Sow., *Pecten quinquecostatus*, Sow., *Belemnitella mucronata*, Schloth. As some of these have the greatest vertical range in Europe, they might be expected more than any others to recur in distant parts of the globe. Even where the species were different, the generic forms, such as *Baculites* and certain genera of *Ammonites*, as also the *Inoceramus* and other bivalves, have a decidedly Cretaceous aspect.

Fish of the genera *Lamna*, *Galeus*, and *Carcharodon* are common to New Jersey and the European Cretaceous rocks. So also is the genus *Mosasaurus* among reptiles. *Hadrosaurus* and *Dryptosaurus* occur amongst the Dinosaurs. Professor O. C. Marsh has described several species of birds from the Greensand of New Jersey.

It appears from the labours of Dr. Newberry and others, that the Cretaceous strata of the United States, east and west of the Appalachians, are characterised by a flora decidedly analogous to that of the Upper Cretaceous of Central Europe, and having considerable resemblance to the vegetation of the Tertiary Period.

Cretaceous rocks are grandly developed in the South-Western States, in Texas, Wyoming, Utah, and Colorado. They are found to the north in Manitoba, and reach to the mouth of the Mackenzie, and into Northern Greenland. In Texas there are limestones with *Hippurites* and *Orbitolites*; but northwards the strata become arenaceous, and were partly deposited in the sea and partly on land. The following are the principal groups. The highest, or Laramie—the Lignitic—is a terrestrial deposit, containing brackish water and some marine fossils, and a vast flora. The vegetation is remarkable for the number of Dicotyledons, showing that this great section of the vegetable kingdom was in existence before the Tertiary age. The Reptilia found in the deposits are mostly Mesozoic in their affinities, and there are no mammalian remains. *Ammonites* and *Inoceramus* have been found. The deposit is 5,000 feet thick on the Green River. The researches of the United States geologists and palæontologists point to the conclusion that the Laramie formation was deposited, at least in part, during the vast period represented by the great break between the Cainozoic and Mesozoic epochs.

The second, or Fox-Hills group, consists of sandstones, some terrestrial and others marine, with *Belemnitella*, *Nautilus*, *Ammonites*, *Baculites*, and *Mosasaurus*. It is from 3,000 to 4,000 feet thick. Thirdly, the Colorado group, with Cretaceous fossils; and fourthly, the Dakota group, with a remarkable flora.

The flora of the Dakota group (Cenomanian) contains ferns of the genera *Lygodium*, *Sphenopteris*, *Pecopteris*, *Gleichenia*, and *Todea*. Amongst the Gymnosperms, the genera *Pterophyllum*, *Sequoia*, *Araucaria*, *Glyptostrobus*, &c.; and *Flabellaria* amongst the palms. There are 167 species of Angiospermous Dicotyledons, of which about one-half are still represented by living species. The order Proteaceæ has three genera —*Proteoides*, *Embothrium*, and *Aristolochites*; and among the Lauraceæ are *Laurus*, *Persea*, *Sassafras*, *Cinnamomum*, *Oreodaphne*; whilst *Magnolia* and *Liriodendron* are amongst the Polycarpieæ. This flora should be carefully noticed, in order that we may not be deceived by the supposition that Dicotyledons of the above-mentioned genera are necessarily of Tertiary age. The flora would at the present time be normal in a climate like that of the South of Europe of from 35° to 40° N. lat. Probably one-half of the Dicotyledons are allied to recent American forms.

According to the most recent researches of Dr. C. A. White, the Cretaceous strata of North America, which are of enormous thickness, belong to an Upper and Lower Cretaceous division, but these

Correlation of the Mesozoic Rocks in different Areas

	—	Britain and Western Europe	The Alps	Russia	North America
CRETACEOUS	Danian	Highest beds of Chalk in Scandinavia and France	—	—	Freshwater strata of Western Territories
	Senonian	Upper Chalk	Hippurite limestones	Chalk Strata of Southern Russia	
	Turonian	Middle Chalk			
	Cenomanian	Lower Chalk and Upper Greensand	Glauconite limestones	—	Greensands of New Jersey
	Albian	Gault			
	Aptian	Lower Greensand	Orbitolite and Requienia limestones		
	Rhodanian & Barremian	Tealby series Speeton Clay, &c.	Limestones and Marls with Belemnites and Aptychi	Limestones of the Balkan Provinces and the Crimea	
	Neocomian (proper)				
JURASSIC	Portlandian	Portland and Purbeck beds	Tithonian		
	Kimeridgian	Kimeridge Clay	Stramberg limestones		
	Corallian	Coral Rag and Calcareous Grit	Diphya limestones	Volga beds	
			—	Zone of *Ammonites alternans*	
	Oxfordian	Oxford Clay	Massive limestones	Zone of *Ammonites cordatus*	
	Callovian	Kelaways Rock			
	Bathonian	Great Oolite	—	Clays of Sambirsk	Newark Formation
	Bajocian	Inferior Oolite	Marls and limestones		
	Toarcian	Midford Sands, &c.	Red Ammonite lmestones		
	Charmonthian	Upper Lias	Limestones with Pygope	Absent	
	Sinemurian	Lower Lias	Red and other Ammonite limestones		
	Hettangian				
	Rhætian	Zone of *Avicula contorta*	Rhætic strata		
TRIASSIC	Tyrolian	Keuper (and Muschelkalk)	Dachstein limestone and Kössen beds	Cephalopod limestones of Siberia	
	Virglorian	Bunter	St. Cassian beds		
	Werfenian	—	Hallstadt beds Dolomites Werfener Schist	(Arcto-Pacific province of Mojsisovics)	

cannot be exactly correlated with the groups of strata bearing the same names in Europe. The Laramie formation is believed to belong, in its upper part, to the Eocene, and in its lower part to the Cretaceous, while the great mass of its beds were probably laid down during the vast interval which separated those periods.

The development of Reptilian life in America during the Cretaceous age was extraordinary. There were very few species of *Ichthyosaurus* in the American area, while these forms abounded in the European Cretaceous strata, and they appear to have been replaced by the Mosasauria. The order Plesiosauria was well represented, but mainly by species of genera related to *Pliosaurus*.

The Mosasauria ruled supreme in the American Cretaceous seas. and Marsh says that some were 60 feet long and others 10 or 12 feet in length. They were swimming lizards with four paddles. Crocodilia, some with biconcave and others with procœlian vertebræ, prevailed during the same age. Allied to the Pterosauria was the genus *Pteranodon*, some species having a spread of wings of from 10 to 25 feet (see fig. 268, p. 251); they replaced the *Pterodactyl* of Europe. The American forms had no teeth, but probably horny beaks like birds and Chelonians. Chelonians existed, but the most remarkable Reptilia found were dwellers on the land, of the group *Dinosauria*. These represented the *Iguanodon* of the Lower Cretaceous of Europe, and the *Dinosaurs* noticed by Seeley in the Maestricht chalk. The Upper-Cretaceous Dinosaurs of America include *Hadrosaurus* of the marine beds and several genera and species, which are found in the strata with Dicotyledonous leaves in the Lignitic series.

For fuller details concerning the Triassic, Jurassic, and Cretaceous strata of the Western Alps, the reader is referred to De Lapparent's excellent 'Traité de Géologie,' third edition, 1898, and for those of the Eastern Alps to Von Hauer's 'Die Geologie der Oester. Ungar. Monarchie,' 1875. The papers of the Mojsisovics and of the late Dr. Neumayr contain admirable discussions concerning the distribution of the Mesozoic forms of life. The North American strata will be found described in the following correlation papers of the U.S. Geological Survey: 'The Newark System,' by J. C. Russell; 'Cretaceous,' by A. C. White. (See also 'The Laramie Formation,' by the same author, 'Bull. U.S. Geol. Soc.' No. 84), and also in Dana's 'Manual of Geology.'

THE NEWER PALÆOZOIC ERA

CHAPTER XX

THE PERMIAN SYSTEM

Subdivisions of the Permian—Permian Marine Fauna of India, Texas, Russia, &c.—Foraminifera—Corals—Brachiopoda—Ammonites and other Cephalopoda—Arthropods—Fish, Amphibians, and Reptiles—Terrestrial Flora—Relations with Carboniferous and Trias respectively—Upper Permian—Magnesian Limestone and Marlslate, with their Fossils—Lower Permian, with its breccias.

Nomenclature and Classification of the Permian strata.—The youngest of the Newer-Palæozoic systems was originally called the Dyas, this name having been applied to it by the German geologists in recognition of the circumstance that in Central Europe the formation consists of *two* very distinct members, and not of three, like the Trias. In 1841, however, Murchison proposed to call this system the Permian, from the circumstance that beds of this age are found covering an enormous area in the Russian province of Perm, and this term is now very generally adopted. Although the terrestrial flora and fauna of the Permian have long been studied by geologists, it is only within the last few years that the remarkable marine fauna, with its strange blending of Mesozoic and Palæozoic types of life, has been made known by the labours of Waagen in India, Gemmellaro in Sicily, Karpinsky in Russia, and White in North America. In the British Islands we have generally, as in the case of the Trias, only red and variegated, unfossiliferous strata representing this great system, an exception being found in the Magnesian Limestone of the North of England first described by Sedgwick. These calcareous strata contain numerous fossils, but their general characteristics have been thought to point to the conclusion that the beds were deposited in great inland salt-lakes rather than in the open ocean.

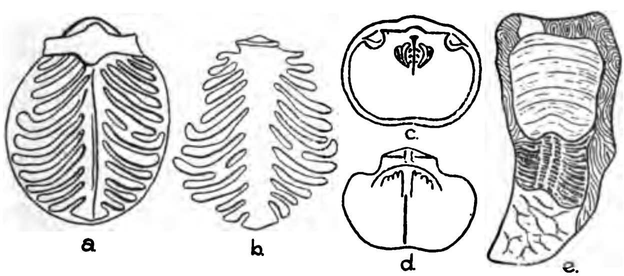
The divisions of the Permian strata in this country may be easily correlated with those of North Germany, as shown in the following table.

North Germany	England
Zechstein with Mergelschiefer and Kupferschiefer.	Upper Permian sandstones and clays with the Marl-slate and Magnesian Limestone at its base.
Roth-todt-liegende.	Lower Permian sandstones, breccias, and conglomerates.

The German name 'Zechstein' (mine-stone) is given to a series of limestones, gypsums, clays, and conglomerates, which had to be penetrated by the shafts put down to reach the Kupferschiefer (copper-slate), a bed at one time worked as a copper-ore. The term Roth-todt-liegende, or 'red dead layers' (often shortened to Roth-liegende), refers to the fact that when these beds were reached all hope of finding further deposits of copper-ore had to be abandoned.

Characteristics of the Permian Fauna and Flora.—The Permian marine fauna, which is now known from the researches

Fig. 452.—Aberrant forms of Brachiopoda from the Permian (Permo-Carboniferous).



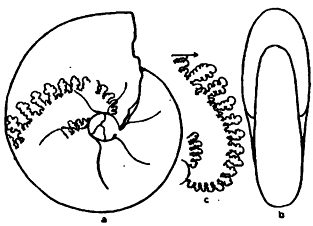
a & *b*. *Oldhamina decipiens*, De Kon. Interior exposed by etching so as to show the peculiar arrangement of the two valves.
a. Ventral valve, internal view.
b. Dorsal valve, from external side.

c, *d*, *e*. *Richthofenia Lawrenciana*, De Kon. sp.
c. View of animal-chamber from above.
d. Small valve (interior).
e. Section of large valve.

carried on in the Salt Range of India, the Alps, Sicily, Russia, and Texas, is a very interesting one, containing a remarkable admixture of Carboniferous (Newer Palæozoic) types with some that are strikingly Mesozoic in their aspect. Among Foraminifera, the characteristic *Fusulina* of the Carboniferous is found in great abundance in the Permian of the Alps and Sicily. The corals of the Permian include Cyathophylloid forms with such Carboniferous genera as *Michelinia*, *Lonsdaleia*, *Pachypora*, &c. The Echinodermata are not numerous, but the Bryozoa are exceedingly abundant, the genus *Fenestella* (fig. 462) being

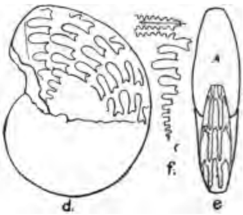
especially well represented. The Brachiopoda in the Permian begin to show that predominance over the Lamellibranchiata, which is so characteristic of all Palæozoic faunas. The ancient types of *Productus* (fig. 463), *Spirifera* (fig. 465), *Athyris*, *Orthis*, *Chonetes*, &c., are accompanied by *Terebratula* and *Rhynchonella*, and a number of genera peculiar to the Permian, such

Fig. 453.



Cyclolobus Oldhami, Waagen.
Permian (Permo-Carboniferous) Salt Range, India.

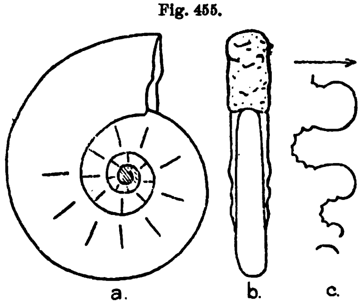
Fig. 454.



Medlicottia Wynnei, Waagen.
Permian (Permo-Carboniferous) Salt Range, India.

as *Strophalosia*, *Camarophoria*, and the remarkably aberrant forms called *Richthofenia* (fig. 452, *c*, *d*, *e*), *Enteletes*, *Lyttonia*, *Oldhamina* (fig. 452, *a*, *b*), &c. The Lamellibranchiata are represented by Palæozoic forms like *Aviculopecten*, mingled with such Mesozoic genera as *Lima*, *Myophoria*, *Gervillia*, *Lucina*, &c.; while among the Gastropoda, *Bellerophon* is still found.

Fig. 455.



Xenodiscus plicatus, Waagen.
From the Permian (Permo-Carboniferous) of the Salt Range, India.

It is in its Cephalopod fauna, however, that the Permian marine strata present such noteworthy characters. The persistent *Nautilus* is represented by numerous highly sculptured forms, while *Orthoceras*, *Gyroceras*, and *Goniatites* of the Palæozoic are found mingled with many true Ammonites (usually marked by a somewhat simple pattern of suture), which have been referred to the peculiar genera *Cyclolobus* (fig. 453), *Medlicottia* fig. 454), *Popanoceras*, *Waagenoceras*, *Xenodiscus* (fig. 455), *Arcestes*, &c., the last-mentioned genus occurring also in the

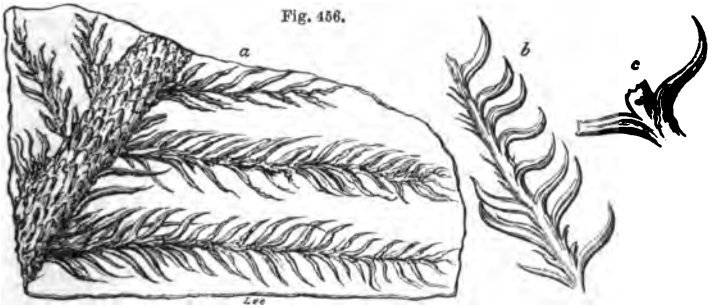
Trias. In some of the Palæozoic Ammonites the sutures are sharply folded like Goniatites, in others we have zigzag lobes with simple curved saddles, like Clymenia, while in others again a complication of suture is found, approaching that of the Mesozoic Ammonites. No representatives of the Mesozoic *Belemnites* have as yet been found in the Permian.

Among Arthropods we have many Ostracoda and some *Estheria*, while one genus of Trilobites (*Phillipsia*) has survived into the Permian.

The chief fish of the Permian are Ganoids, all with heterocercal tails, such as *Palæoniscus*, *Platysomus*, *Acrolepis*, *Amblypterus*, *Acanthodes*, &c. But some Selachians of very aberrant type also occur.

Amphibians of the order Stegocephala (Labyrinthodontia), which are so abundant in the Trias, are also found in great

Fig. 456.



Walchia piniformis, Schloth. Permian, Saxony. Nat. size.
a. Branch. *b*. Twig of the same. *c*. Leaf magnified.

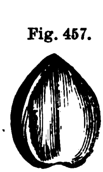
numbers in the Permian. These Stegocephala are curious synthetic forms combining many of the characters of the existing Amphibians and Reptiles. A great number of strangely varied forms of this group have been described by Dr. Anton Fritsch in Bohemia, and by Prof. H. Credner in Saxony.

True Reptiles are represented by Rhynchocephalians (*Palæohatteria*), Lacertilians (?) (*Proterosaurus*, a synthetic type combining many of the characters of the lizards and crocodiles), and the earliest known examples of the Theriomorpha (*Naosaurus*, *Pariasaurus*, &c.)—the remarkable group of Reptiles showing certain affinities with the Amphibians on the one hand, and the Mammalia on the other. Dinosaurs, Ichthyosaurians, Plesiosaurians, and Pterosaurians are all at present unknown in the Permian, nor have any traces of birds or mammals been found in it.

The Terrestrial flora of the Permian is fairly well known. It is Palæozoic and not Mesozoic in its main characteristics. Ferns and Calamites, with numerous Conifers, occur in it, but Stigmarieæ are rare, and Sigillarieæ and Lepidodendreæ seem to have entirely disappeared. Forms of Cordaiteæ (*Cordaioxylon*) also occur. Among genera largely represented in the Permian may be mentioned the fern *Callipteris*, and the conifer *Walchia* (fig. 456). The Ginko (*Salisburia*) of the existing flora makes its appearance as early as the Permian.

About 18 or 20 species of plants are known in the Permian rocks of England. None of them pass down into the Carboniferous series, but several genera, such as *Alethopteris*, *Neuropteris*, and *Walchia*, are common to the two groups. *Caulopteris*, *Lepidodendron*, *Calamites*, and *Sternbergia* are Lower Permian and Carboniferous genera, and fragments of coniferous wood have been found with them. The Permian flora on the Continent appears, from the researches of MM. Murchison and De Verneuil in Russia, and of MM. Geinitz and Von Gutbier in Saxony, to be moderately distinct from that of the Coal, fifty species being common to both formations. But the Permian flora is characterised by the genus *Callipteris*, which is not Carboniferous, and by a profusion of tree-ferns of the genus *Psaronius*, of *Equisetites*, and by the abundance of *Walchia*.

Fig. 457.



Cardiocarpon Ottonis, Gutbier. Permian, Saxony. ½ diameter.

Fig. 458.

Noeggerathia cuneifolia, Brong.

In the Permian rocks of Saxony no less than sixty species of fossil plants have been met with. Several of these, as *Calamites gigas*, Brong., and two species of *Sphenopteris*, are also met with in the Government of Perm, in Russia. Seven others, and among them *Neuropteris Loshii*, Brong., *Pecopteris arborescens*, Brong., and several species of *Walchia* (see fig. 456), and a genus of Conifers called *Lycopodites* by some authors, are said by Geinitz to be common to the Coal-measures.

Among the Permian genera are the fruit called *Cardiocarpon* (see fig. 457), *Asterophyllites*, and *Annularia*, with *Lepidodendron* and *Calamites*; so characteristic of the Carboniferous Period; also *Noeggerathia* (fig. 458), the leaves of which have parallel veins without a mid-rib, and to which various generic synonyms, such as *Cordiates*, *Flabellaria*, and *Poacites*, have been given, is another link between the Permian and Carboniferous vegetation. Coniferæ, of the Araucarian division, also occur; but these are likewise met with both in older and newer rocks. The plants called *Sigillaria* and *Stigmaria*, so marked a feature in the Carboniferous period, are as yet wanting in the true Permian.

Among the remarkable fossils of the Rothliegende or lowest part of the Permian in Saxony and Bohemia, are the silicified trunks of tree-ferns called generically *Psaronius*. Their bark was surrounded by a dense mass of air-roots, which often constituted a great addition to the original stem, so as to double or quadruple its diameter. The same peculiarity is found in certain living extra-tropical arborescent ferns, particularly those of New Zealand.

Thus we see that while, upon the whole, the plants of the Marl-slate or Middle Permian differ from those of the Coal Period, the plants of the Rothliegende of Germany which belong to the Lower Permian begin to show a very close generic affinity with Carboniferous forms.

Myriapods and insects have been found in considerable numbers, and some at least of the remarkable Amphibians and Reptiles of the period must be regarded as belonging to the terrestrial fauna.

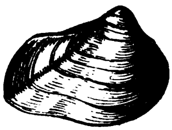
British Representatives of the Permian System

Upper Permian.—The Upper Member of the British Permian is seen to attain its chief thickness in the north-west or on the coast of Cumberland, as at St. Bees' Head, where it is described by Sir Roderick Murchison as consisting of red sandstones and red clays with gypsum resting on a thin course of Magnesian Limestone with fossils, which again is connected with the Lower Red Sandstones, resembling the Upper beds, in such a manner that the whole forms a continuous series. No fossil footprints have been found in this Upper, although they have been detected in the Lower Sandstone.

Middle Permian—Magnesian Limestone and Marl-slate. This formation is seen upon the coast of Durham and Yorkshire, between the Wear and the Tees. Among its characteristic fossils are *Schizodus Schlotheimi*, Gein. (fig. 459), and *Mytilus septifer*, King (fig. 461). These shells occur at Hartlepool and Sunderland, where the rock assumes a concretionary and botryoidal character. Some of the beds in this division are ripple-marked. In some parts of the coast

of Durham, where the rock is not crystalline, it contains as much as 44 per cent. of magnesium carbonate, mixed with calcium carbonate. In other places—for it is extremely variable in character—it consists chiefly of calcium carbonate, and has concreted into globular and hemispherical masses, varying from the size of a marble to that of a cannon-ball, with radiated structure. Occasionally earthy

Fig. 459.

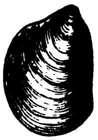


Schizodus Schlotheimi, Gein, $\frac{2}{3}$.
Magnesian limestone.

Fig. 460.

The hinge of *Schizodus truncatus*, King.
Permian.

Fig. 461.

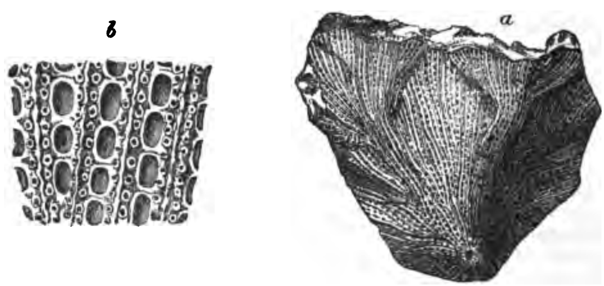


Mytilus septifer, King, nat. size. Syn. *Modiola acuminata*, Sow. Magnesian limestone.

and pulverulent beds pass into compact limestone or hard granular dolomite. Sometimes the limestone appears in a brecciated form, the fragments which are bound together consisting not of foreign rocks, but formed by the breaking-up of the Permian limestone itself, about the time of its consolidation. Some of the angular masses in Tynemouth Cliff are two feet in diameter.

The magnesian limestone sometimes becomes fossiliferous and includes in it delicate Bryozoa, one of which, *Fenestella retiformis*, Schloth. (fig. 462), is a very variable species, and has received many

Fig. 462.



a. Fenestella retiformis, Schloth. sp., nat. size.
Syn. *Retepora flustracea*, Phillips.
b. Part of the same highly magnified.

Magnesian Limestone, Humbleton Hill, near Sunderland.

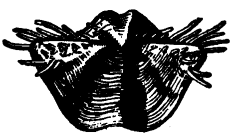
different names. It sometimes attains a large size, single specimens measuring 8 inches in width. This Bryozoan, and four other species are common to England and the Permian of Germany.

The total known fauna of the Permian series of Central Europe at present numbers 300 species, of which more than half are mollusca. Not one of these is common to rocks newer than the

Palæozoic, and the Brachiopoda are the only group which have furnished species common to the more ancient or Carboniferous rocks. There are few Gasteropods. The Cephalopoda are, *Nautilus Freieslebeni*, Gein., found also in the German Zechstein, and species of *Orthoceras*.

With regard to the Brachiopoda, shells of the genera *Productus* (fig. 463) and *Strophalosia* (the latter an allied form with hinge teeth), which do not occur in strata newer than the Permian, are abundant in the ordinary yellow magnesian limestone. They are accompanied by certain species of *Spirifera* (fig. 465) and *Lingula*

Fig. 463.

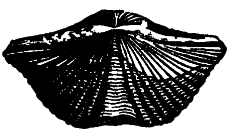


Productus horridus, Sowerby, ½. Sunderland and Durham, in Magnesian Limestone. Zechstein and Kupferschiefer, Germany.

Fig. 464.

Lingula Credneri, Gein. Magnesian Limestone and Carboniferous. Marl-slate, Durham; Zechstein, Thuringia.

Fig. 465.



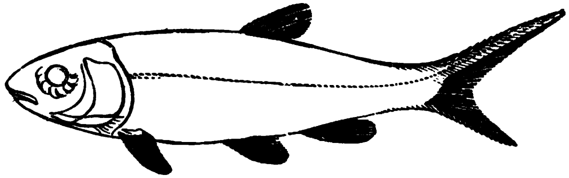
Spirifera alata, Schloth., ⅔. Sow. King's Monogr. Magnesian Limestone.

Credneri, Gein. (fig. 464). Some of the Permian Brachiopoda, such as *Camarophoria* (allied to *Rhynchonella*), *Spiriferina*, and two species of *Lingula*, are specifically the same as some fossils of the Carboniferous rocks. *Avicula*, *Arca*, and *Schizodus* (fig. 459), and other Lamellibranchiate bivalves, are abundant.

The Magnesian Limestone has yielded, in England, only 100 species of fossils, of which the Brachiopoda number 21, the Lamellibranchs 31, the Gasteropoda 26, and fish 21 species.

Beneath the limestone lies a formation termed the Marl-slate, which consists of hard, fissile, calcareous shales, and thin-bedded

Fig. 466.



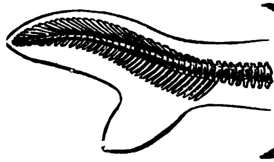
Restored outline of a fish of the genus *Palæoniscus*, Agass.

limestones. At East Thickley, in Durham, where it is thirty feet thick, this slate has yielded many fine specimens of fossil fish—of the genera *Palæoniscus* 10 species, *Pygopterus* 2 species, *Cœlacanthus* 2 species, and *Platysomus* 2 species, which, as genera, are common to the older Carboniferous formation; but the Permian species are peculiar, and, for the most part, identical with those found in the Marl-slate or Copper-slate of Thuringia.

The *Palæoniscus* above mentioned belongs to that division of

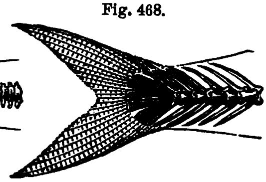
fishes called by Agassiz 'Heterocercal,' which usually have their tails unequally bilobate, like the recent Shark and Sturgeon, and the vertebral column running along the upper caudal lobe. (See fig. 467.) The 'Homocercal' fish, which comprise the greater number of

Fig. 467.



Shark.
Heterocercal.

Fig. 468.



Shad. (*Clupea.* Herring tribe.)
Homocercal.

species at present found living, have the tail-fin either single or equally divided; and the vertebral column stops short, and is not prolonged into either lobe. (See fig. 468.) Now it is a singular fact,

SCALES OF FISH. MAGNESIAN LIMESTONE.

Fig. 469.

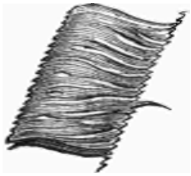


Fig. 470.

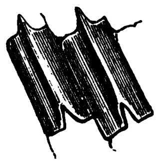


Fig. 471.

Fig. 472.

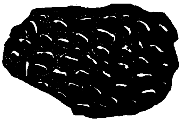
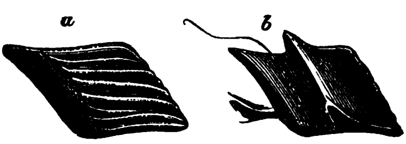


Fig. 469. *Palæoniscus comptus*, Ag. Ganoid scale, magnified. Marl-slate.
Fig. 470. *Palæoniscus elegans*, Sedgw. Under surface of ganoid scale, magnified. Marl-slate.
Fig. 471. *Palæoniscus glaphyrus*, Ag. Under surface of ganoid scale, magnified. Marl-slate.
Fig. 472. *Cœlacanthus granulatus*, Ag. Granulated surface of scale, magnified. Marl-slate.

Fig. 473.



Pygopterus mandibularis, Ag. Marl-slate.
a. Outside of scale, magnified.
b. Under surface of same.

Fig. 474.

Acrolepis Sedgwickii, Ag.
Outside of scale, magnified.
Marl-slate.

first pointed out by Agassiz, that the heterocercal form, which is confined to a small number of existing genera, is universal in the Magnesian Limestone and all the more ancient formations. It characterises the earlier periods of the earth's history, whereas

in the secondary strata, or those newer than the Permian, the homocercal tail greatly predominates.

In Professor King's monograph on the Permian fossils a full description has been given by Sir Philip Egerton of the species of fish characteristic of the marl-slate; and figures of the ichthyolites, which are very entire and well preserved, will be found in the same memoir. Even a single scale is usually so characteristically marked as to indicate the genus, and sometimes even the particular species. They are often scattered through the beds singly, and may be useful to the geologist in determining the age of the rock.

Two species of *Proterosaurus*, a genus of reptiles, have been discovered in the marl-slate, one representative of which, *P. Speneri*, Meyer, has been celebrated ever since the year 1810 as characteristic of the Kupferschiefer or Permian of Thuringia. Remains of a Labyrinthodont, *Lepidotosaurus Duffi*, Hancock and Howse, have been met with in the same slate near Durham; and a quarry in the Permian sandstone of Kenilworth has yielded the skull of another species, called by Professor Huxley *L. Dasyceps*, on account of the roughness of the surface of the cranium.

Lower Permian.—The principal development of the British Lower Permian is found in the north-west of England, where the Penrith sandstone, as it has been called, and the associated breccias and purple shales are estimated by Professor Harkness to attain a thickness of 3,000 feet. Organic remains are generally wanting, though footprints and worm-tracks are occasionally met with, and the leaves, cones, and wood of coniferous plants have been found in beds considered by Professor Harkness to be the equivalent of the marl-slate which overlies the Penrith sands at Hilton. In the red sandstones of this age at Corncockle Muir, near Dumfries, very distinct footprints occur in great number and variety. No bones of the animals which they represent have yet been discovered, but a cranium of *Dasyceps* has been found further south.

Angular Breccias in Lower Permian.—A striking feature in these beds is the occasional occurrence, especially at the base of the formation, of angular and sometimes rounded fragments of Carboniferous and older rocks of the adjoining districts. These are included in a red matrix. Some of the angular masses are of huge size. These brecciated conglomerates are well seen in the Abberley Hills, where they are 400 feet thick.

Sir A. Ramsay refers the angular form and large size of the fragments composing these breccias to the action of floating ice in the sea. The angular masses of rock, sometimes weighing more than half a ton, and lying confusedly in a red unstratified marl, like stones in boulder drift, appear in some cases to be polished, striated, and furrowed like erratic blocks in the moraine of a glacier. They can be shown, in some instances, to have travelled from the parent rocks, thirty or more miles distant, and yet not to have entirely lost their angular shape.

The monograph on Permian fossils, by the late Prof. King, contains figures and descriptions of the chief British Permian forms of life. The plants have been described by Von Gutbier and other palæophytologists. Dr. Waagen's memoir on the Salt Range fossils, published by the Geological Survey of India, must be referred to for figures and descriptions of the very remarkable marine forms.

CHAPTER XXI

THE CARBONIFEROUS SYSTEM

Succession of Strata in the Carboniferous System—Carboniferous Foraminifera and Corals, Echinodermata, Brachiopoda, Lamellibranchiata, Gastropoda and Cephalopoda of the Period—Carboniferous Fishes and Amphibians—The Carboniferous Flora—Peculiarity in Mode of Growth of the Cryptogams of the Period—Ferns, Calamites, Lepidodendra, &c. —Land-shells and Insects of the Carboniferous Period—Carboniferous Strata of Britain—Coal-measures—Millstone Grit—Carboniferous Limestone and Yoredale Series—Tuedian Series—Scottish Carboniferous—Calciferous Sandstone Series—Mode of Formation of the Carboniferous Strata—Coal-seams, Ironstones, &c.—Marine and Freshwater Strata of Carboniferous.

Nomenclature and Classification of the Carboniferous strata.—This system of strata has received its name from the circumstance that, in Western Europe and the United States, most of the productive coal-seams occur among deposits of this age. The beds of coal vary in thickness from an inch, or even less, up to thirty feet or more, and alternate with various thicker strata of sandstone and shale, with occasional bands of limestone and argillaceous ironstone. Such assemblages of coal-bearing strata are called by the old English miners' name of 'coal-measures.' The coal-measures are usually found occupying basin-shaped hollows, owing to their having been thrown into synclinal curves by great earth movements. The intervening anticlinals having been removed by denudation, we often find the coal-bearing strata forming isolated patches, which are known as 'Coalfields;' but these must not be mistaken for lake-like depressions in which deposition has taken place. The coal-measures sometimes contain marine fossils, at other times brackish-water forms, and sometimes purely freshwater ones. The remains of land-plants occur in the coal itself, and in the sandstones, shales, and ironstones alternating with the coal; in the same strata we occasionally find the remains of freshwater amphibians, fish, crustaceans, land-shells, and even of insects.

The coal-measures alternate, however, with thick deposits of limestone, shale and sandstone, which abound with purely marine types of life.

In South Wales and the Bristol and Somersetshire coal-fields the general succession of strata in the Carboniferous system is as follows:—

1. Coal-measures[1]	Upper series of sandstones, shales, and 26 coal-seams. Pennant grit and 15 coal-seams. Lower coal-measures with ironstone and 34 coal-seams.
2. Millstone grit	A coarse quartzose sandstone used for millstones. 400 feet shale called 'Farewell Rock.'
3. Carboniferous or Mountain limestone	A calcareous rock containing marine shells, corals, and encrinites. Thickness variable: 2,000 feet. Lower limestone shale 400 feet.

This threefold division of the Carboniferous is a purely local one, however. When we pass southwards into Devonshire, we find thick masses of strata (the Culm-measures) containing carbonaceous matter but no workable seams of coal. As we proceed northwards we find that, though the general distinction between the arenaceous division in the middle of the series (Millstone grit) and the strata above and below it respectively can still be recognised, the distribution of productive coal-seams is remarkably different. In Yorkshire thin seams of coal are found in the midst of the Millstone-grit series, and in the Lancashire and West Yorkshire district the Carboniferous Limestone Series is broken up into alternations of limestones, shales, and sandstones with some beds of coal, known as the Yoredale Series. Further north, in the parts of Northumberland near the Scottish Border, we find coal-beds present right down to the base of the Carboniferous Limestone division, forming the Tuedian Series, while in Scotland itself similar coal-seams are found from top to bottom of the Carboniferous system, and even in the great masses of sandstone (Calciferous Sandstone) which there underlie the representatives of the Carboniferous Limestone.

It is worthy of notice that the highest strata of the Carboniferous (the Coal-measures) in the coal-fields of the West of England (Warwickshire, Staffordshire, and Coalbrook Dale) rest directly upon the older rocks, no representatives of the Carboniferous Limestone division having been deposited in that area. In Ireland, on the other hand, the lower portion of the Carboniferous series (Carboniferous Limestone and Carboniferous Slate) cover wide areas, while the upper members (the Coal-

[1] It will be seen that the term 'coal-measures' is used not only for any assemblage of coal-bearing strata, but as a distinctive name for the highest member of the Carboniferous series. The term 'millstone grit' is given to the middle member, as some of the coarse sandstones were at one time used for millstones, and the name 'mountain limestone' to the lowest member, from its forming the mountains of Derbyshire and the West Riding of Yorkshire.

measures) were either never deposited, or have been almost entirely removed by denudation.

In some areas the coal-fields are bordered by great faults, in others they are buried under masses of Permian and other younger strata. Where these covering strata are not of too great thickness, the coal-beds are reached by sinking shafts through them.

A great ridge of ancient rocks including infolded basins of Coal-measures extends under the Mesozoic strata of the East and South-east of England, and has been reached by borings at several points (Burford, Northampton, Harwich, and Dover); the same strata reappear in the North of France and the South of Belgium, the coals being worked by shafts put down through the Chalk or other Mesozoic formations.

Characteristics of the Carboniferous Fauna and Flora. The marine fauna of the Carboniferous, which is found especially in the thick limestones in the lower part of the series, is a very rich one.

Fig. 475.

Fusulina cylindrica, Fisch. Magnified 3 diam. Mountain Limestone.

Among the Foraminifera we find that living genera like *Textularia* and *Nodosaria* are mingled with extinct forms like *Endothyra* and *Fusulina*. The forms of the last-mentioned genus are particularly noteworthy; they are fusiform bodies, about the size of a grain of barley, which sometimes build up massive limestone rocks in Russia, Asia Minor, Japan, and North America. These Fusulina-limestones of the Carboniferous resemble the Nummulite-limestones of the Eogene; and, indeed, the two genera Nummulina and Fusulina have close affinities with each other.

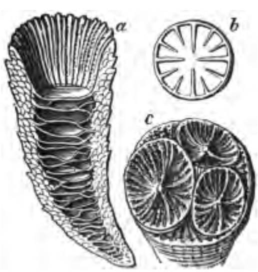
The Corals were, during this period, represented only by forms of the now extinct Tetracoralla (Rugosa); the Hexacoralla of the Mesozoic and Tertiary rocks and of our modern seas having come into existence in later times than the Carboniferous. Many remarkable examples of these Rugose corals are found in the Mountain Limestone, among which may be mentioned *Amplexus*, *Lonsdaleia* (fig. 479), *Lithostrotion* (fig. 478), *Zaphrentis*, &c.

Other coral-like forms of this system are referred to the extinct order of the Tabulata (Monticuliporida), which appear to have relations both with the Bryozoa and the Actinozoa.

Among the Echinodermata many forms of Crinoidea abound, their ossicles often making up great beds of limestone (Entrochial-limestone). These Palæozoic Crinoids, like *Actinocrinus*, *Cyathocrinus* (figs. 480, 481), *Platycrinus*, &c., differ in many

Fig. 476.

Palæozoic type of lamelliferous cup-shaped Coral. Order TETRACORALLA.



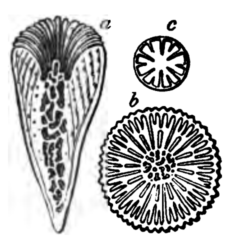
a. Vertical section of *Cyathophyllum flexuosum*, Goldf.; ½ nat. size; from the Devonian of the Eifel. The septa are seen around the inside of the cup; the walls consist of cellular tissue; and large transverse plates, called *tabulæ*, divide the interior into chambers.

b. Arrangement of the septa in *Polycœlia profunda*, Germar, sp.; nat. size; from the Magnesian Limestone, Durham. This diagram shows the quadripartite arrangement of the primary septa, characteristic of palæozoic corals, there being 4 principal and 8 intermediate lamellæ, the whole number in this type being always a multiple of four.

c. *Stauria astræiformis*, Milne-Edwards. Young group, nat. size. Silurian, Gothland. The lamellæ or septa in each cup are divided by four prominent ridges into four groups.

Fig. 477.

Neozoic type of lamelliferous cup-shaped Coral. Order HEXACORALLA.

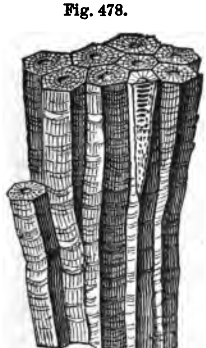


a. *Parasmilia centralis*, Mantell, sp. Vertical section; nat. size. Upper Chalk, Gravesend. In this type the *lamellæ* extend to the columella composed of loose cellular tissue, and there are no *tabulæ*.

b. *Caryophyllia Bowerbankii*, Ed. and H. Transverse section, enlarged. Gault, Folkestone. In this coral the primary septa are a multiple of six. The six primary and six secondary septa reach the columella, and between each pair of long septa there is a tertiary septum with a quaternary on either side, in all forty-eight. The short intermediate plates which proceed from the columella are called *pali*.

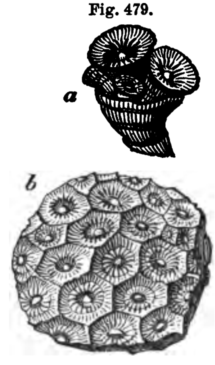
c. *Fungia patellaris*, Lam. Recent; very young state. Diagram of its six primary and six secondary septa, magnified.

Fig. 478.



Lithostrotion basaltiforme, Phil. sp., ½. England; Ireland; Russia; Iowa, and westward of the Mississippi, United States.

Fig. 479.



Lonsdaleia floriformis, Mart. sp., ½.
a. Young specimen, with buds or corallites on the disk, illustrating calicular gemmation. *b.* Part of a full-grown compound mass.

important points of their structure from the living Crinoids and those of the Cainozoic and Mesozoic times.

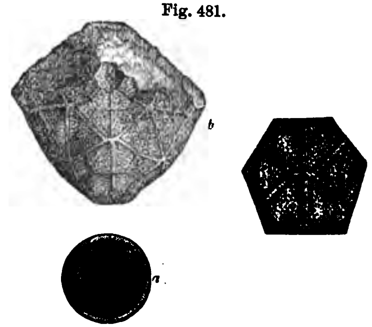
A remarkable extinct order of Echinodermata, the Blastoidea, is represented by many forms of *Pentremites* (fig. 482), *Granatocrinus*, &c., while the ordinary Echini are replaced by the

Fig. 480.

Cyathocrinus planus, Miller.

Body and arms.
Mountain Limestone.

Fig. 481.



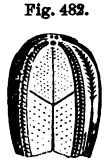
Cyathocrinus caryocrinoides, M'Coy.

a. Surface of one of the joints of the stem.
b. Pelvis or body; called also calyx or cup.
c. One of the pelvic plates.

curious extinct order Palæchinidea, including *Palæchinus* (fig. 483), *Archæocidaris* and *Melonites*, in which we find the ambulacra not separated by two rows of plates, as in all the living and Mesozoic forms, but by five or more rows.

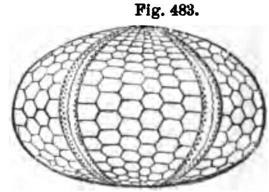
Bryozoa are very abundant in some portions of the Carboniferous limestone of England and Scotland. The most

Fig. 482.



Pentremites ellipticus, Sow., $\frac{2}{3}$. Carb. Limestone, Derbyshire, &c.

Fig. 483.



Palæchinus gigas, M'Coy, ½. Reduced one-third. Carboniferous Limestone. Ireland.

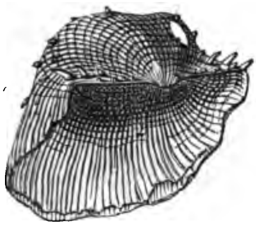
abundant genera are the extinct ones, *Fenestella*, *Polypora*, *Diastopora*, and *Glauconeme*.

Among the Brachiopoda, *Productus* (fig. 484) is the most abundant genus in the Carboniferous; but many forms of *Spirifera*, both ribbed and smooth types (figs. 485, 486), occur with species of *Chonetes*, *Orthis*, *Athyris*, *Rhynchonella*, &c. The

oldest form of *Terebratula* (fig. 487), a genus so characteristic of the Mesozoic, is found in the Carboniferous.

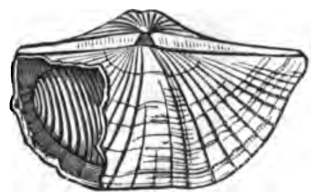
The Lamellibranchiata, which are present in much smaller

Fig. 484.



Productus semireticulatus, Mart. sp., ½. Carboniferous Limestone. England; Russia; the Andes, &c.

Fig. 485.



Spirifera trigonalis, Mart. sp., nat. size. Carboniferous Limestone. Derbyshire, &c.

Fig. 486.

Spirifera glabra, Mart. sp., ⅓. Carboniferous Limestone.

Fig. 487.

Terebratula hastata, Sow., ⅔, with radiating bands of colour. Carboniferous Limestone. Derbyshire; Ireland; Russia, &c.

Fig. 488.

Aviculopecten papyraceus, Goldf., ½. (*Pecten papyraceus*, Sow.)

Fig. 489.

Aviculopecten sublobatus, Phill., nat. size. Carboniferous Limestone. Derbyshire; Yorkshire.

Fig. 490.

Pleurotomaria carinata, Sow., ⅔. (*P. flammigera*, Phill.) Carboniferous Limestone. Derbyshire, &c.

numbers than in younger rocks, are principally represented by purely Palæozoic genera like *Aviculopecten* (figs. 488, 489), *Conocardium*, *Cardiomorpha*, *Edmondia*, *Anthracosia*, *Cypricardinia*, *Posidonomya*, &c.

With a few Mesozoic types of Gastropoda, *Natica*, *Pleurotomaria* (fig. 490), *Chiton*, &c., we find great numbers of extinct Palæozoic types, which have usually entire (holostomatous) apertures, such as *Macrocheilus*, *Loxonema*, &c., and also the

Fig. 491.

a b c d

Euomphalus pentangulatus, Sow., $\frac{2}{3}$. Mountain Limestone.

a. Upper side. *b*. Lower or umbilical side. *c*. View, showing mouth, which is less pentagonal in older individuals.
d. View of polished section, showing internal chambers.

Fig. 492.

Bellerophon costatus, Sow., nat. size. Mountain Limestone.

Fig. 493.

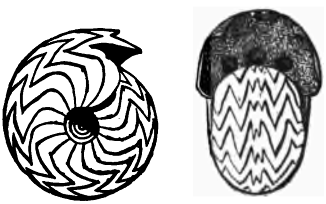
Portion of *Orthoceras laterale*, Phill., $\frac{1}{2}$. Mountain Limestone.

remarkable *Euomphalus* (fig. 491), a Gastropod with its shell divided by imperforate septa, and *Bellerophon*, which probably belonged to the Heteropoda.

The Cephalopoda of the Carboniferous are of great interest,

and present a remarkable contrast to those of the Mesozoic rocks. The persistent Nautiloidea are found, but represented by various subgenera with channelled or tuberculated shells, while the forms of straight or slightly curved forms, *Orthoceras* (fig. 493), *Cyrtoceras*, &c., are very abundant. True Ammonites

Fig. 494.



Goniatites crenistria, Phill., ⅔.
Mountain Limestone.
N. America; Britain; Germany, &c.

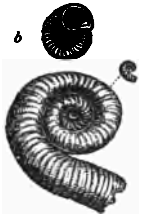
a. Lateral view.
b. Front view, showing the mouth.

Fig. 495.

Goniatites Listeri, Mart., ⅔.
Coal-measures, Yorkshire and Lancashire.

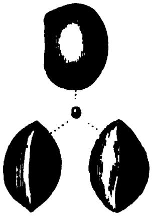
are quite unknown, but the group of the Ammonoidea is represented in the Carboniferous by many forms of *Goniatites* (figs. 494, 495), some of which are of simple structure and allied to the older Devonian types, while others begin to show the greater complication of lobes indicative of the later *Ceratites*.

Fig. 496.



a Microconchus (*Spirorbis*) *carbonarius*, Murch.
Nat. size and magnified.
b. Variety of same.

Fig. 497.



Leperditia inflata, Murch. sp.
Nat. size and magnified.
A Carboniferous Ostracod.

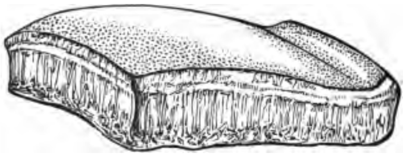
The Vermes were represented by the minute *Microconchus* (*Spirorbis*), which is often found attached to fragments of the vegetation of the period which had floated in the ocean.

Among the Arthropods, a few Decapod Crustaceans are found in the Carboniferous, with numerous Limulids (*Prestwichia*, *Belinurus*, &c.), and some Phyllopods, Isopods, and Ostracods.

Many limestone bands in the Carboniferons system are

found to be completely made up of the remains of these minute bivalve Crustacea, and the surfaces of many of the shales are covered with them. Among the genera which occur in the greatest abundance are *Leperditia* (fig. 497), *Carbonia*, *Beyrichia*, *Cytherella*, and *Kirkbya*.

Fig. 498.



Psammodus porosus, Ag. Bone-bed, Mountain Limestone. Bristol; Armagh.

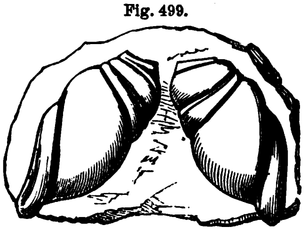
The sole survivors of the abundant *Trilobites* of the older systems are the genera *Phillipsia*, *Griffithides*, and *Brachymetopus*, the first-mentioned of which survived to Permian times.

Of the fish of the period we find numerous remains in the fine spines (ichthyodorulites) and palatal teeth of the Selachians: *Psammodus* (fig. 498), *Cochliodus* (fig. 499), *Orodus*, *Gyracanthus*, *Ctenacanthus*, &c.

Heterocercal ganoids, like *Palæoniscus*, *Acrolepis*, &c., abound, while forms of the Dipnoi (*Ctenodus*) are also found.

Amphibians are represented by a few early types of Stegocephala, a group which attained such a remarkable development in Permian and Triassic times, while Reptilia and all higher groups are unknown in the Carboniferous.

Fig. 499.



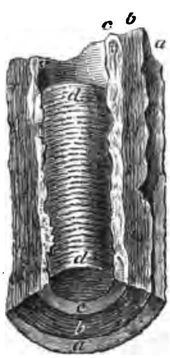
Cochliodus contortus, Ag. Bone-bed, Mountain Limestone. Bristol; Armagh.

It is, however, the Terrestrial flora and fauna of the Carboniferous which are of such great geological importance. Interest attaches to the Coal-measure flora not only on account of the remarkable differences which it presents, alike from the Mesozoic, the Cainozoic, and the existing floras, but from the circumstance that it is the oldest assemblage of land plants of which at present we have any knowledge.

Although many of the Carboniferous plants are only represented by casts and impressions or thin coaly films, often showing the outer markings on bark or leaves with great fidelity, yet the internal structure of many of these ancient plants has been very

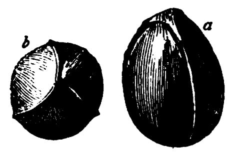
fully investigated by the late Professor W. C. Williamson and other botanists. The manner in which this is accomplished is by making thin sections of the 'coal-balls,' or masses of woody tissue impregnated with calcium carbonate, which are found in some beds of coal, and comparing these with sections of living plants under the microscope. One of the chief difficulties in studying the ancient plants of the Carboniferous period arises from the circumstance that we only find detached portions of many of them, and it is now known that the bark, leaves, root, stem, pith, and fructification of the same coal-plants have often

Fig. 500.



Fragment of coniferous wood, *Dadoxylon*, Endl., fractured longitudinally; from Coalbrook Dale. W. C. Williamson.
a. Bark.
b. Woody zone or fibre (pleurenchyma).
c. Medulla or pith.
d. Cast of hollow pith or 'Sternbergia.'

Fig. 501.



Trigonocarpon ovatum, Lindl. and Hutt. Peel Quarry, Lancashire.

Fig. 502.

Trigonocarpon olivæforme, Lindl., with its fleshy envelope. Felling Colliery, Newcastle.

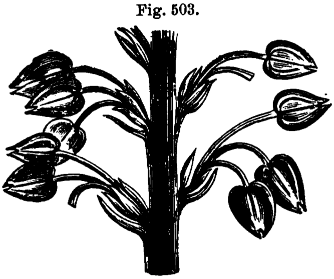
been referred to as many distinct genera. Such mistakes can only be rectified when we have the rare good fortune to find these various parts of the plant united in the same specimen.

So far as is at present known, there were no forms of vegetable life present in the Carboniferous higher in the scale than the Conifers. Numerous varieties of wood like the *Dadoxylon* (fig. 500), Araucarioxylon, &c., are found having the characteristic exogenous structure of the Conifers, with the peculiar pitted vessels of that group. The fossil fruits so abundant in some parts of the Coal-measures, and known as *Trigonocarpon*, have the very closest analogy too with the fruit of the Ginko (*Salisburia*),

(a remarkable genus of the Yew tribe having some affinities with the Gnetaceæ), of which the leaves are found in the Permian.

Other forms of Gymnosperms found in the Carboniferous are more doubtful in their relationships. In some silicified fruits occurring in the Carboniferous of France, Brongniart showed that we have a curious combination of characters now found in the groups of the Cycads, the Conifers, and the Gnetaceæ; and it is not improbable that the earliest plants of this group were synthetic types, in which the differentiation of characters found in existing forms did not exist.

Fig. 503.

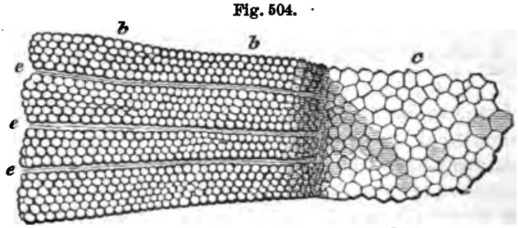


Cardiocarpon Lindleyi, Carr. (*Antholithes*, Lind.) Coal-measures, Falkirk.

Cordaites with large simple parallel-veined leaves is referred to an extinct order which is believed to have been related to the existing Cycads.

With the exception of these aberrant Gymnosperms, the plants of the Carboniferous period appear to have belonged to the Cryptogams, or plants propagated by means of spores. Some of them were homosporous (like Lycopodium), and others were heterosporous (like Selaginella), but nearly all of them presented a remarkable peculiarity in their mode of growth which distinguishes them from all living Cryptogams. While all living Cryptogams are 'Acrogens' and grow by additions to their summit only, the Cryptogams of Carboniferous times were able to increase by an

Fig. 504.



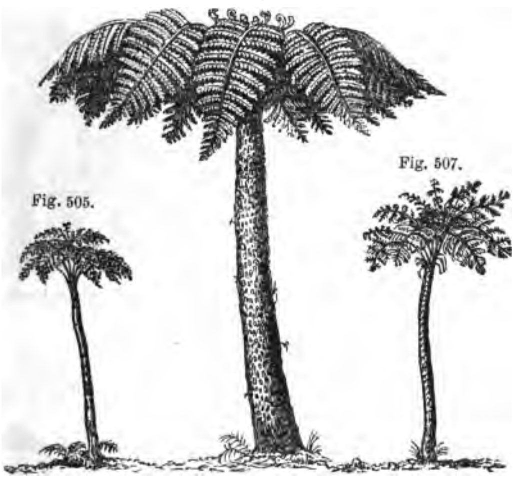
c. Pith. *b.* Wood. *e, e, e.* Medullary rays.

exogenous growth like the Conifers and the higher dicotyledonous plants. In all of these we have a bark and pith, united by plates of cellular tissue known as 'medullary rays,' between which the wedge-like masses of woody tissue are developed. Each year a layer of 'cambium' is formed between the woody

axis and the bark, and thus an addition is made to the diameter of the trunk. It has now been fully demonstrated that this mode of growth was followed by the Cryptogams of the Carboniferous period, and in consequence of this peculiarity they were able to assume the characters and dimensions of great forest-trees.

The exact analogies of many of the gigantic Cryptogams of the Carboniferous are still very doubtful. Many ferns undoubtedly existed, some of which attained the size of the largest

Fig. 506.



Living tree-ferns of different genera. (Ad. Brong.)
Fig. 505. Tree-fern from Isle of Bourbon.
Fig. 506. *Cyathea glauca*, Borg., Mauritius.
Fig. 507. Tree-fern from Brazil.

tree-ferns. In the Carboniferous ferns we find the characteristic venation of the leaves or fronds; similar arrangements of the spore-cases upon them; and the same vernation, or mode of rolling up of the leaves, which are found in existing forms. The trunks of these ferns are often marked by scars, as in *Caulopteris* (fig. 509), and they frequently exhibit aerial root-like stems, like *Psaronius*. Some at least among them appear to have had the same exogenous mode of growth that distinguished the other primitive Cryptogams of the period. Williamson and Scott have recently described synthetic forms intermediate between Ferns and Cycads.

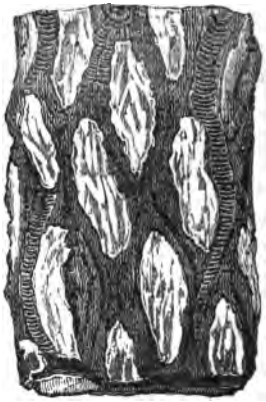
Another group of Carboniferous Cryptogams is believed to

have been related to the insignificant Equisetaceæ of our ponds and ditches. These *Calamites*, however, exhibit the exogenous mode of growth and attained to vast dimensions. Often only

Fig. 508.

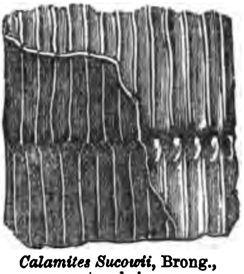
Pecopteris elliptica, Bunb., nat. size.

Fig. 509.



Caulopteris primæva, Lindl., ½.

Fig. 510.



Calamites Sucowii, Brong., natural size.
Common in coal throughout Europe.

Fig. 511.

Stem of fig. 510, as restored by Sir W. Dawson.

Fig. 512.

Radical termination of a Calamite.
Nova Scotia.

the cast of the interior is preserved in a fossil state, though sometimes the woody matter remains reduced to a thin shell of coal.

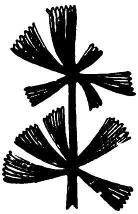
Masses of whorled leaves referred to the genera *Annularia* (fig. 513), *Sphenophyllum* (fig 514), and *Asterophyllites* (fig. 515), are believed by some botanists to have belonged to plants with Calamite-like stems, but the reasons given for the identification are not in all cases satisfactory.

The greater number of the gigantic Cryptogams of the Carboniferous period appear to have been related to the existing

Fig. 513.

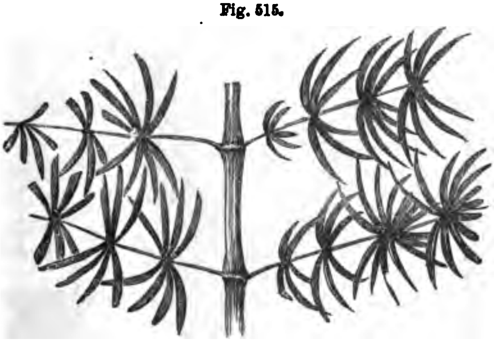
Annularia sphenophylloides, Zenk.

Fig. 514.



Sphenophyllum erosum, Lindl. and Hutt.

Fig. 515.

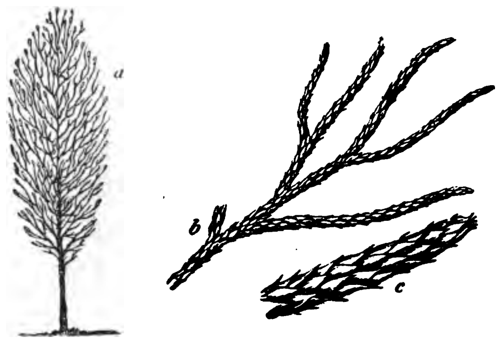


Asterophyllites foliosus, Lindl. and Hutt. Coal-measures, Newcastle.

Lycopods and Selaginellas. But while these modern plants usually creep along the ground and the erect forms are only a few inches in height, the *Lepidodendra* of the Carboniferous formed great trunks rising to a height of forty or fifty feet and exhibiting an exogenous structure. The ancient forms exhibit a dichotomous mode of branching and the peculiar scars on their stems which mark the position of the leaflike appendages. But what is of more importance to the botanist is the circumstance that we find the fruits or cones (*Lepidostrobus*) some-

times attached to the branches of the plant and exhibiting all the peculiarities of the heterosporous *Selaginella*, both macrospores and microspores being present in them.

Fig. 516.



a. Lycopodium densum, Labill. Living species. New Zealand.
b. Branch; natural size. *c.* Part of same, magnified.

Fig. 517.

Fig. 518.

Fig. 519.

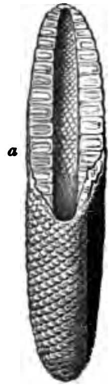
Lepidodendron Sternbergii, Brong. Coal-measures, near Newcastle.

Fig. 517. Branching trunk, 49 feet long, supposed to have belonged to *L. Sternbergii.* (Foss. Flo. 203.)
Fig. 518. Branching stem with bark and leaflets of *L. Sternbergii*, $\frac{2}{3}$. (Foss. Flo. 4.)
Fig. 519. Portion of same nearer the root. Natural size. (Ibid.)

Other closely related forms, presenting a different pattern of leaf-scars, have been called *Sigillaria*; but it is very doubtful if the form and arrangement of the leaf-scars constitute a safe basis of classification in these ancient forms of vegetation.

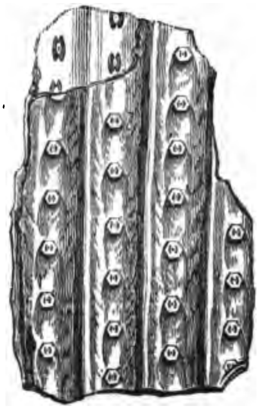
The stems of both Lepidodendra and Sigillariæ are some-

Fig. 520.



a. *Lepidostrobus ornatus*, Brong. (Strobilus or cone), Shropshire; ½ nat. size.
b. Portion of a section showing the large sporangia in their natural position.
c. Microspores occurring in these sporangia, highly magnified.

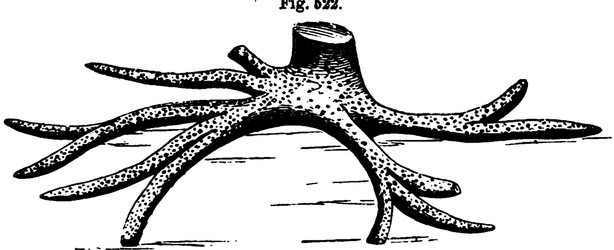
Fig. 521.



Sigillaria lævigata Brong.

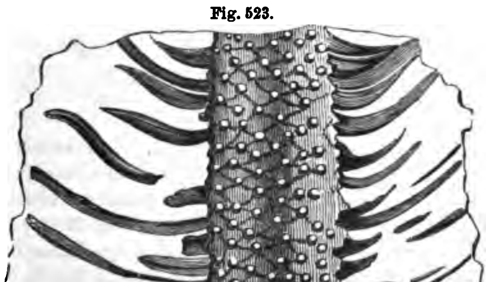
times found attached to large dichotomously branching root-stocks, known as *Stigmaria*. These forms are illustrated in the figures below.

Fig. 522.



Stigmariæ attached to a trunk of *Sigillaria*.

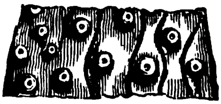
Fig. 523.



Stigmaria ficoides, Brong. ¼ natural size. (Foss. Flo. 32.)

In considering the terrestrial flora of the Carboniferous system, it must be remembered that the plants preserved in a fossil state are nearly all such as would grow in marshy flats like those found in the deltas of great rivers. Of the plants that may have flourished in the higher ground at the same period we have comparatively little knowledge; but in some of the beds of Carboniferous Sandstone great trunks of Coniferous trees fifty or sixty feet in length have been found, occupying an inclined position; these were probably trees that had been carried down by rivers and formed 'snags' like those seen in the Mississippi at the present day. Among plants found in a fossil state, purely herbaceous forms would have little chance of being included. That even the lowly cellular plants, represented by delicate filaments, existed in the Carboniferous period is proved by the circumstance pointed out by the late Dr. P. M. Duncan and other authors that the calcareous organisms of the Carboniferous (Corals, Echinoderms, and Mollusca) are often found to be penetrated by fine cavities produced by these parasitic algæ.

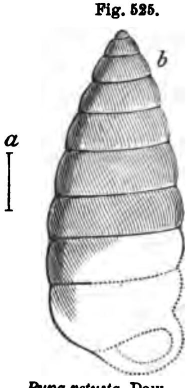
Fig. 524.



Surface of another individual of same species, showing form of tubercles.

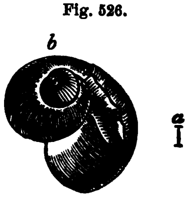
The terrestrial fauna associated with this remarkable flora of the Carboniferous is of great interest, though as yet very imperfectly known. In Nova Scotia Sir J. W. Dawson has discovered in the hollows of old tree-trunks representatives of the oldest known land-shells (pulmoniferous gastropoda) which have been referred to *Pupa* (fig. 525) and *Zonites* (fig. 526). And associated with these remains of the oldest Myriapoda are Arachnida (Spiders and Scorpions); while many forms of insects abounded in the Carboniferous. Some of the insects were closely related to

Fig. 525.



Pupa vetusta, Daw.
a. Natural size.

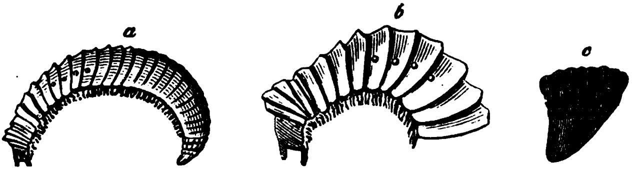
Fig. 526.



Zonites (*Conulus*) *priscus*, Carpenter.
b. Magnified.

the Coleoptera (Beetles), the Orthoptera (Cockroaches, Crickets, &c.) (fig. 527), the Neuroptera (Ants, &c.), and other living orders; but others seem to have been curious synthetic types for which naturalists have been compelled to establish new orders.

Fig. 527.

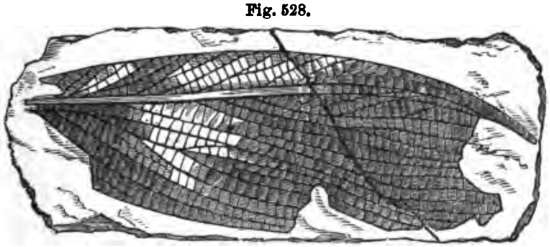


Xylobius Sigillariæ, Dawson. Coal, Nova Scotia and Great Britain.
a. Natural size. *b.* Anterior part, magnified. *c.* Caudal extremity, magnified.

Air-breathing vertebrates were probably represented in the Carboniferous by Stegosauria (Labyrinthodonts) of very simple structure, like the *Dendrerpeton* of North America, and the Archegosaurus (fig. 529) and other European forms.

Of some of the latter not only the skeletons, but impressions of the skin have been described by H. von Meyer (fig. 530).

Fig. 528.



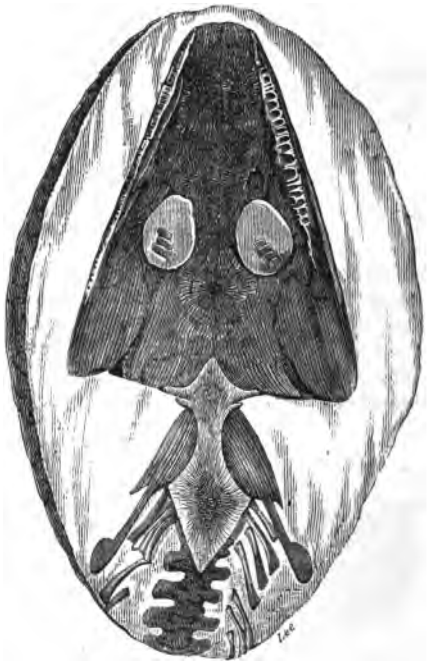
Wing of a Grasshopper, *Gryllacris lithanthraca*, Goldenb., nat. size. Coal, Saarbrück, near Trèves.

In North America footprints of animals of considerable size are sometimes found on the surfaces of sandstone slabs that are also traversed by sun-cracks. The footprints were probably those of air-breathing animals, possibly Amphibians, like those of which the bones have been found. It is interesting to notice also that the Carboniferous rocks present examples of rain-prints and worm-tracks, exactly similar to those which can be seen on muddy shores at the present day (figs. 531–532).

British representatives of the Carboniferous Strata.—The rapid changes in the thickness and characters of the British Carboniferous have been already referred to. In Devonshire we find

what is known as the 'Culm facies' of the Lower Carboniferous, consisting of alternations of hard shales, impure limestones and grey-wackés, with much carbonaceous matter, but no useful coal-beds. In the south-western group of coal-fields (South Wales, Bristol, and

Fig. 529.



Archegosaurus minor, Goldf. Fossil Amphibian from the Coal-measures, Saarbrück.

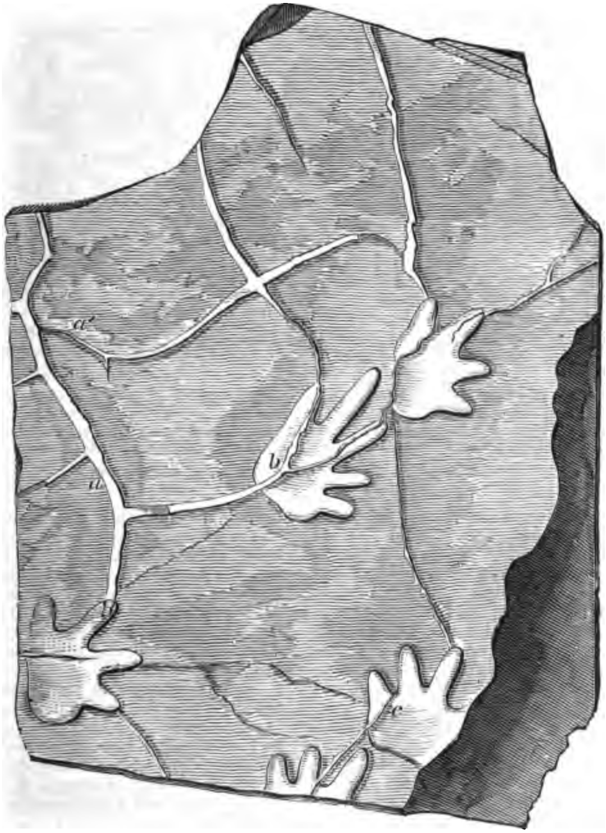
Fig. 530.

Imbricated covering of skin of *Archegosaurus medius*, Goldf. Magnified.

Somerset, Forest of Dean, and Mendip Hills) the Lower Carboniferous strata are of moderate thickness, while the upper beds of the system (Coal-measures) attain an enormous thickness. The strata, which are often much bent and folded, include many coals poor in hydrocarbons

(steam-coals) and also anthracites. These coal-fields present a close analogy with those of Northern France, Belgium, and Westphalia. In the Midland coal-fields (Staffordshire, Warwickshire, Leicestershire, Coalbrook Dale, &c.) the Lower Carboniferous is generally absent, and

Fig. 531.



Scale one-sixth the original.

Slab of sandstone from the Coal-measures of Pennsylvania, with footprints of air-breathing amphibian and casts of cracks.

the Coal-measures rest directly upon the older rocks. In the Yorkshire and the Lancashire and Cheshire coal-fields, the Lower Carboniferous attains a great thickness, consisting of purely marine strata (Carboniferous limestone and shale) in the southern part of the area, which alternate with more and more freshwater and terrestrial beds

as we pass northwards. In Scotland estuarine beds with coal are found from the top to the bottom of the series, and even in the arenaceous division (Calciferous sandstone) which in the northern part of Great Britain forms the lowest member of the Carboniferous system.

Fig. 532. Fig. 533.

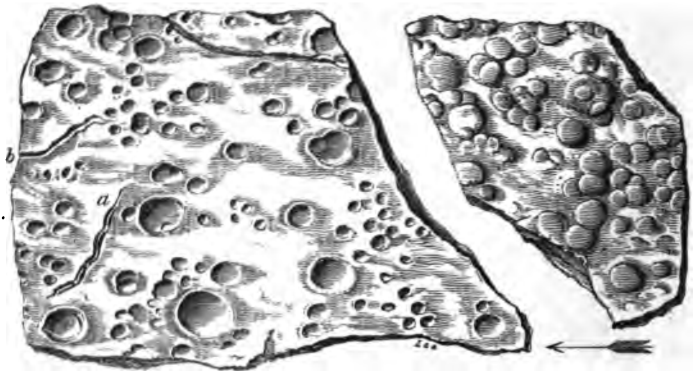


Fig. 532. Carboniferous rain-prints with worm-tracks (*a*, *b*) on green shale, from Cape Breton, Nova Scotia. Natural size.
Fig. 533. Casts of rain-prints on a portion of the same slab (fig. 532), seen to project on the under side of an incumbent layer of arenaceous shale. Natural size.

The arrow represents the supposed direction of the shower.

General notice of the divisions.—The Coal-measures of the North of England differ, to a certain extent, from those of the south-west; but a typical series would include the following strata, beginning at the top. 1. Red and grey sandstones, clays, and sometimes breccias, with occasional coal-seams and streaks of coal and *Spirorbis*-limestone with *Leperditia inflata*, Murch. sp. 2. Middle coals, yellow sandstones, clays, and shales, with numerous workable coal-seams resting on fire-clays: fossils, *Anthracosia*, *Anthracomya*, *Beyrichia*, *Estheria*, *Spirorbis*. 3. Lower beds, gannister beds, flagstones, shales, and thin coals, with hard siliceous layers beneath the coal-seams. Flagstones intercalated. Fossils, *Aviculopecten*, *Lingula*, *Goniatites*, *Orthoceras*. Bone-bed, with fish and Labyrinthodonts.

In Scotland the equivalents of the uppermost beds above mentioned are probably a red sandstone group without coals, overlying workable (flat) coals, and in the North-west of England these beds are barren here and there, as at Wigan; but at Manchester they are important and coal-bearing. At Burnley, on the other hand, the beds are absent.

The Millstone grit, well seen in South Wales, is grandly developed beneath some Coal-measures, and feebly beneath others, or it may be wanting. For along a line drawn from Shropshire through South Staffordshire and Leicestershire, to the Wash, a ridge of Palæozoic rocks existed in Carboniferous times, on which little or usually no marine accumulation took place. Hence the Coal-measures at Coalbrookdale, South Staffordshire, rest upon Silurian rock with a very little or no gannister grit intervening.

This ridge of old rocks, or 'central barrier,' was a Carboniferous land-surface, and the

grits collected on either flank, increasing in thickness far away to the north and west, and attaining a thickness of 9,000 feet in North Staffordshire, 12,130 feet in South Lancashire, and 18,700 feet in North Lancashire.

The thickness of the grits at the edge of the Staffordshire coal-field is only 200 feet, and it is 3,000 feet in Western Yorkshire.

The grits vary greatly in their lithology. Some are very rough and massive, others are fine-bedded micaceous sandstones and flags, whilst the bulk are jointed or are strata of varying thicknesses, and with the grains distinctly visible. All the sandstones are felspathic, and the grains are often united by a felspathic matrix. The area whence the grits came, carried by marine currents, was in the north-west. Thin coal-seams and coal-plants are found in some places in the grits, and sometimes a marine fauna exists, including fossils of the same species as those found in the lower strata called Carboniferous limestone.

The grits are divided into the Rough Rock, or first grit, which underlies the lower Coal-measures; the Flag Rock or Haslingdon Flags, or second grit, with shales and thin coal; the third grit of gritstone, flagstone shale, and thin coals, with marine fossils; the Kinderscout grit, or fourth grit: this last forms the Peak in Derbyshire.

In Scotland the Moor-rock, with thin seams of coal, is the equivalent of the English grits, and its very moderate thickness diminishes in Ayrshire, where it consists of a few beds of sandstone at the base of the Coal-measures.

Carboniferous Limestone series.—In Yorkshire there is a downward continuation of sandstones and shales, resembling those of the Millstone grits with intercalated limestones, some of which are thickly crowded with encrinites. Phillips called these the Yoredale series, and they attain the thickness of from 800 to 1,000 feet in Yoredale. The genera of marine fossils which are found in these strata are *Nautilus*, *Orthoceras*, *Phragmoceras*, *Goniatites*, *Euomphalus*, *Bellerophon*, *Productus*, *Spirifera*, *Phillipsia*, *Zaphrentis*, &c., and these are common in the underlying carboniferous limestone. Beds of thin coals occur in the lower Yoredale strata. These strata are not found in the Centre and South of England, where the true Mountain or Carboniferous limestone exists.

This important limestone, well seen in Derbyshire, South Wales, and Somerset, is massive, well bedded, and light-bluish, grey, reddish, or black in colour, and it may be either compact or crystalline. The limestones are thickest where the grits above are thinnest, and have suffered much denudation where they are at the surface. The fossils contained in them are very numerous, and in some places encrinites compose much of the rock, whilst Foraminifera are equally abundant elsewhere. The base of this important set of strata varies locally. In South Wales and Somersetshire the lower part merges into a shale—Lower Limestone shale—and this into bottom beds of yellow and green sandstones and marls with plant-remains, and a bone bed with *Placoid* fish-remains. This rests on Old Red Sandstone. In some parts of Yorkshire there are alternations of sands and clays at the base with plant-remains, and in the west of the county conglomerates form the base, and rest upon Silurian rocks—the Old Red Sandstone of the south-west not being present. Elsewhere, either the base of the limestone has not been seen, or it rests on very old rocks without the intervention of any beds of shale.

In Central England, where the other sedimentary beds are reduced to about 3,000 feet, the Carboniferous Limestone attains an enormous thickness, and, according to Mr. Hull's estimate, as much as 4,000 feet at Ashbourne, near Derby. To a certain extent, therefore, we may consider the calcareous member of the formation as having originated simultaneously with the accumu-

lation of the materials of grit, sandstone, and shale, with seams of coal; just as strata composed of mud, sand, and pebbles, several thousand feet thick, with layers of vegetable matter, are now in process of formation in the cypress swamps and delta of the Mississippi, while coral reefs are simultaneously forming on the coast of Florida, and in the sea of the Bermuda Islands. For we may safely conclude that in the ancient Carboniferous ocean those marine animals which secreted calcium carbonate were never freely developed in areas where the rivers poured in fresh water charged with sand or clay; and the limestone could only become several thousand feet thick over parts of the ocean bed which were being slowly depressed, the water remaining perfectly clear for ages.

The Carboniferous Limestone, with its associated Yoredale series, diminishes in thickness northwards, and undergoes remarkable changes in its lithology and fossils. In Northumberland, beds of coal are found right down to the bottom of the representatives of Lower Limestone and Shale, constituting what is known as the 'Tuedian Series.' In Scotland Sir A. Geikie notices that the massive limestones dwindle down and are replaced by thick courses of yellow and white sandstone, dark shale, and seams of coal and ironstone. Limestone beds are met with in thin sheets only. The whole formation is divided into the Carboniferous limestone and the underlying Calciferous sandstones. These last-mentioned strata consist of red and yellow sandstones with many-coloured marls, which pass insensibly into the Upper Old Red Sandstone beneath. They are very unfossiliferous, but *Sphenopteris affinis*, Lindl., is common. Above the red sandstones is the Cement-stone group, of different coloured sandstones, shales, oil shales, and argillaceous limestones. In the West of Scotland these beds are poor in fossils. In the area of the Firth of Forth the Cement-stone group contains ironstones, seams of coal, oil shales, and sandstones; and these last contribute to the building materials of Edinburgh. The oil shales yield petroleum on distillation.

Amongst the limestones of the group are the Burdie House limestones, composed of the tests of an Ostracod Crustacean, *Leperditia Okeni*, Munst., and containing fish, of which *Megalichthys* is a prominent form.

Seams of coal occur, and one called the Houston coal is worked in Linlithgowshire. *Sphenopteris*, *Lepidostrobus*, *Araucarioxylon*, and *Lepidodendron* are found in them.

The Carboniferous limestone group of Scotland probably represents the upper part of the English limestone in age, and consists of a few seams of encrinital limestone, shales, fire-clays, and seams of coal. The thickest of the limestones, the Hurlet, is in places 100 feet thick; it overlies a seam of coal and pyritous shales, and above it are other important coal-seams and ironstones. These last contain marine fossils, and the coals have plants and fish-remains and those of Labyrinthodontia. Some of the limestone-seams are very persistent over wide areas.

In Ireland the Carboniferous rocks of the North have their lower series like the Scottish Calciferous sandstones. But in the southern districts there is a deep group of black and dark-grey shales, impure limestones, and grey and green grits with slates, which overlie the Old Red Sandstone, and are beneath the base of the Carboniferous limestone. This group is the Carboniferous slate. Its age is not quite certain; it may be either the equivalent of the Lower-limestone shale of the South-west of England or be part of the Devonian formation. The Carboniferous limestone covers a large part of Ireland, and it alternates with sandstones towards the north.

Deposition of the Carboniferous formation.—It has been mentioned (p. 868) that Coal-measures rest upon Silurian and old rocks in some parts of the

central barrier. This was the land of the age in the first instance. The sea flowed in upon the Old-Red-Sandstone terrestrial area, north of the Bristol Channel, and to the north of the central barrier also, and the shales and sandstones of the lowest marine deposits accumulated. Further north there was a land vegetation, at times, during this age.

Sinking of the greater part of the area continued, probably along lines of fault, and a considerable depth of limestone was formed, and, as time elapsed, this became an arenaceous deposit in Yorkshire and northwards. Here and there were land-surfaces, and coal-plants accumulated and formed coal. In Scotland the depression persisted, but silting up of the sea-floor, and volcanic disturbances and ejections, enabled the terrestrial surfaces to be formed over and over again. Then came a long period of wear and tear of land, mostly situated in the north-west, and the age of the Millstone Grit set in. Even during its time there were a few land-surfaces which produced coal. Subsequently the depression still continued, and the deep Coal-measures accumulated.

The amount of volcanic energy displayed was great at certain epochs of the Carboniferous age, and will be noticed further on.

Lastly, enormous curving and dislocation of the Carboniferous rocks, and great denudation of their exposed surfaces, took place. Thousands of feet of Coal-measures were worn off before the deposition of the Permian rocks, and subsequently. It would appear that after the deposition of the Coal-measures, a thrust acted from north to south and south to north, forming great curvatures of the strata, the long axes being east and west. Denudation occurred, and the Permian deposits accumulated. Then curving occurred in the opposite direction, the axes of the curved strata being north and south. Hence more or less basin-shaped areas were produced; and denudation wore off and displayed the edges of the underlying grits and limestones on the edge of the several basins.

The term Coal-field is applied to an area where coal is visible at the surface at its edges or outcrops, or where it is not too deeply seated to be worked. There are about twenty principal coal-fields in Great Britain, and several smaller ones. Some of these form complete basins, entirely circumscribed by the lower members of the formation, others have one part of the basin visible, the rest being covered up by Permian or other strata, and the rest are bounded by faults.

Coal formed on land.—In South Wales, where, as already pointed out, the Coal-measures attain a great but variable thickness, the sandstones and shales appear to have been formed in water of moderate depth, during a slow, but perhaps intermittent, depression of the surface, in a region to which rivers were bringing a never-failing supply of muddy sediment and sand. The same area was alternately covered with vast forests, such as we see in the deltas of great rivers in warm climates, which are liable to be submerged beneath fresh or salt water, should the land sink vertically a few feet.

In one section, near Swansea in South Wales, where the total thickness of the Coal-measures is 3,246 feet, we learn from Sir H. de la Beche that there are ten principal masses of sandstone. One of these is 500 feet thick, and the whole of them make together a thickness of 2,125 feet. They are separated by masses of shale, varying in thickness from 10 to 50 feet. The intercalated coal-beds, sixteen in number, are generally from 1 to 5 feet thick, one of them, which has two or three layers of clay interposed, attaining 9 feet. At other points in the same coal-field the shales predominate over the sandstones. Great as is the diversity in the horizontal extent of individual coal-seams, they all present one characteristic feature, in having, each of them, what is called its *underclay*. These underclays, coextensive with every layer of coal, consist of arenaceous shale, sometimes called fire-clay, because it can be made into bricks which

stand a furnace-heat. They vary in thickness from 6 inches to more than 10 feet, and, as Sir William Logan pointed out, are characterised by enclosing the peculiar fossil plant called *Stigmaria*. It was also observed that, while in the overlying shales or 'roof' of the coal, ferns and trunks of trees abound, without any *Stigmaria*, and are flattened and compressed, those singular plants of the underclay most commonly retain their natural forms, unflattened and branching freely, sending out their slender rootlets in all directions. A number of species of *Stigmaria* were known to botanists, and described by them, before their position under each seam of coal was pointed out, and before their true nature as the roots of trees (some having been actually found attached to the base of *Sigillaria* stumps) was recognised.

Now that all agree that these underclays are ancient soils, it follows that where we find them they attest the terrestrial nature of the plants which formed the overlying coal, which consists of the trunks, branches, and leaves and spores of the plants which had their roots in the clay. The trunks have generally fallen prostrate in the coal, but some of them still remain at right angles to the ancient soils (see fig. 64, p. 60).

Professor Göppert, after examining the fossil plants of the coal-fields of Germany, has detected, in beds of pure coal, remains of every family of plants of which representatives occur fossil in the Carboniferous rocks. Many seams, he remarks, are rich in *Sigillaria*, *Lepidodendron*, and *Stigmaria*, the latter in such abundance as to appear to form the bulk of the coal. In some places, almost all the plants were *Calamites*, in others ferns.

Between the years 1837 and 1840, six fossil trees were discovered in the coal-field of Lancashire, where it is intersected by the Bolton Railway. They were all at right angles to the plane of the bed, which dips about 15° to the south. The distance between the first and the last was more than 100 feet, and the roots of all were embedded in a soft argillaceous shale. In the same plane with the roots is a bed of coal, 8 or 10 inches thick, which was found to extend across the railway, to the distance of at least ten yards. Just above the covering of the roots, yet beneath the coal-seam, so large a quantity of the *Lepidostrobus variabilis*, Lindl., was discovered, enclosed in nodules of hard clay, that more than a bushel was collected from the small openings around the base of some of the trees. The exterior trunk of each was marked by a coating of friable coal, varying from one quarter to three-quarters of an inch in thickness; but it crumbled away on removing the matrix. The dimensions of one of the trees is 15½ feet in circumference at the base, 7½ feet at the top, its height being 11 feet. All the trees have large spreading roots, solid and strong, sometimes branching, and traced to a distance of several feet, and presumed to extend much further.

In a colliery near Newcastle a great number of specimens of *Sigillaria* occur in the rock, retaining the position in which they grew. Not less than thirty, some of them 4 or 5 feet in diameter, were visible within an area of 50 yards square, the interior being sandstone, and the bark having been converted into coal. (See fig. 65, p. 60.)

It has been remarked that if, instead of working in the dark, the miner were accustomed to remove the upper covering of rock from each seam of coal, and to expose to the day the soils on which ancient forests grew, the evidence of their former method of growth would be obvious.

Where coal occurs on Gannister—a gritty sandstone—there is no underclay, and usually marine remains are found above the seam. In this instance, the vegetation did not grow where it became mineralised, but was carried by water-power from some other locality and deposited.

The numerous coal-seams occurring one over the other, in a

series of often 10,000 feet of vertical measurement, indicate that the plants grew on a rapidly subsiding area, into which the sea occasionally penetrated.

There are also coal-seams composed of the variety known as 'Cannel coal' (called also 'parrot-coal' in Scotland, from the noise it gives out in burning), which appears not to have been formed directly from growing plants, but from the black peaty mud derived from their decay and partial decomposition. If the black muds formed by the bursting of peat mosses were to collect in hollows and undergo induration and chemical change, a material would probably be produced not very dissimilar to Cannel coal. The Cannel coals often contain a very large proportion of ash, and thus pass insensibly into the highly bituminous shales known as oil-shales, from the fact that when heated in retorts they yield various petroleum oils. Many of these, like the rock of Torbane Hill (Torbanite), are of considerable economic value.

In some parts of the earth's crust the destructive distillation of carbonaceous rocks has resulted from natural processes, and accumulations of liquid hydrocarbons (natural oils) and of gaseous hydrocarbons (natural gas) have taken place. Deep borings sometimes tap these accumulations, and then jets of oil or emanations of gas issue at the surface and can be collected and utilised for purposes of illumination and heating. Some of these natural oils and gases are connected with the rocks of Carboniferous age, but others are found in association with strata of very different age.

Clay-ironstone occurs as bands and nodules or in thin layers in the Coal-measures, and they are formed, says Sir H. de la Beche, of ferrous carbonate mingled mechanically with earthy matter, like that constituting the shales. The nodules have generally formed around some organic object, and in some instances, like the Mussel-band ironstone, the valves of a shell of a mollusc have been converted into ferrous carbonate. Robert Hunt found that decomposing vegetable matter, such as would be distributed through all coal strata, prevented the further oxidation of the ferrous salts, and converted the peroxide into protoxide by taking a portion of its oxgyen to form carbon dioxide. Such carbon dioxide meeting with the protoxide of iron in solution, would unite with it and form a ferrous carbonate; and this mingling with fine mud, when the excess of carbon dioxide was removed, might form beds or nodules of argillaceous ironstone.

Marine beds intercalated in Coal-measures.—In the coal-fields, both of Europe and America, the association of freshwater, brackish-water, and marine strata with coal-seams of terrestrial origin is frequently recognised. Thus the upper member of the Coal-measures noticed on p. 368 was formed under brackish-water and marine conditions. The characteristic fossils are a small bivalve, having the form of a *Cyclas* or *Cyrena*, also a small Ostracod, *Leperditia inflata*, Murch., and the shell of a minute tubercular annelid of an extinct genus called *Microconchus* (fig. 496) allied to *Spirorbis*. In many coal-fields there are freshwater strata, some of which contain shells termed *Anthracosia* and *Anthracomya*, now referred to freshwater groups like the *Unionidæ* of the present day; but in the midst of the coal-series of Yorkshire and other districts we find thin and sometimes widely distributed seams abounding in the remains of fishes and marine shells like *Orthoceras*, *Goniatites Listeri*, Sow., and *Aviculopecten papyraceus*, Goldf. These facts show that in the estuaries in which the coal-seams were probably formed the sea occasionally broke in and sometimes occupied the area for a greater or less length of time.

A very full account of the several coalfields of the British Islands has been given by Professor Hull in his 'Coal-fields of Great Britain.' Fuller details on many questions connected with the Carboniferous strata will be found in the Report of the Coal Commission, 1871, and in the following Memoirs of the Geological Survey: 'The Yorkshire Coal-field,' by Prof. A. H. Green; 'The Leicestershire Coal-field,' by E. Hull; 'The Geology of Edinburgh,' by H. H. Howell and A. Geikie, and in the various English treatises on Geology.

CHAPTER XXII

THE DEVONIAN SYSTEM

Relations of the Devonian—Devonian Corals, Brachiopoda, Cephalopoda, and Trilobites—The Devonian Fish and their Relationships to Living Forms—The Devonian Flora and its Relation to that of the Carboniferous—Devonian Strata of Devon and Cornwall—Upper, Middle, and Lower Devonian—Old Red Sandstone—Relations to Devonian—Proof of Freshwater Origin—Old Red Sandstone of Scotland, Lower, Middle, and Upper—Old Red Sandstone of England and Wales—Old Red Sandstone of Ireland.

Nomenclature and classification of the Devonian strata. The name of Devonian was first proposed by Lonsdale for the series of strata underlying the Culm-measures in Devonshire, the fossils of which, as he showed, present many analogies with those of the Carboniferous on the one hand, and with those of the Silurian on the other hand, but are clearly distinct from those of both these systems. The fossils of the British Devonshire strata are, however, not very numerous, and are generally badly preserved; but in Central Germany, and especially in the Eifel district, rocks of the same age are found crowded with the most beautiful and exquisitely preserved fossils. Hence some authors have preferred to call this system of strata by the name of 'Eifelian,' but the older term Devonian is now almost universally employed by geologists.

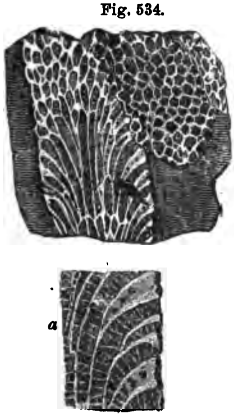
In most parts of the British Islands, however, we find between the Carboniferous and Silurian strata a series of red sandstones, with conglomerates, argillaceous beds, and impure concretionary limestones, which contain no marine fossils but yield the remains of fish, crustaceans, land-plants, and, more rarely, of freshwater mollusca. From their relations we may infer that these strata—which, from their position below the coal-bearing rocks, are known as the Old Red Sandstone—are, speaking generally, contemporaneous (homotaxial) with the Devonian marine strata. This conclusion is confirmed by the fact that certain fish and crustaceans are common to the two sets of strata. We thus find side by side beds of marine and fresh-

water origin deposited during the same geological period—the former constituting the Devonian and the latter the Old Red Sandstone.

Characteristics of the Devonian Faunan ad Flora.—In the Devonian strata we find not only those obscure impressions which may possibly represent seaweeds, but well-preserved portions of gigantic Laminarians, to which the name of *Nematophycus* has been given.

Both in Devonshire and the Eifel, Corals are particularly

Fig. 534.

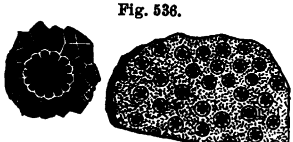


Favosites cervicornis, Blainv., nat. size. S. Devon, from a polished specimen. A Tabulate Coral.
a. Portion of the same magnified, to show the tabulæ and pores.

Fig. 535.

Heliophyllum Halli, E. & H. A Rugose Coral. Middle Devonian. After Nicholson.

Fig. 536.

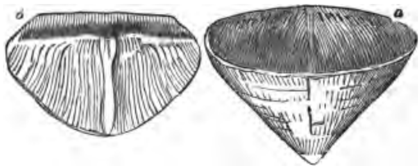


Heliolites porosa, Goldf. sp., nat. size.
a. One of the corallites magnified. Middle Devonian, Torquay. Plymouth, Eifel.

abundant, and they nearly all belong to the group of the Tetracoralla (Rugosa). Among the common forms in the Devonian may be mentioned *Favosites* (fig. 534), various forms of Cyathophyllids (like *Heliophyllum*, fig. 535), *Heliolites* (fig. 536), and the curious and highly characteristic operculate corals *Calceola* (fig. 537), which were formerly mistaken for Brachiopods. With the true Corals are found many other coral-like structures, like the Monticuliporida, which are probably allied to the Bryozoa, and the Stromatoporoidea, usually grouped with the Hydrozoa.

The Graptolites, which are so abundant in the Older Palæozoic rocks, are only represented by a few doubtful forms in the Devonian.

Fig. 537.

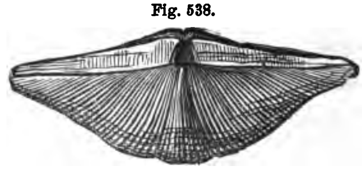


Calceola sandalina, Lam., $\frac{2}{3}$. Eifel; also South Devon.
a. Ventral valve. *b*. Inner side of dorsal valve.

The Crinoids of the Devonian period are rare in Devonshire but very abundant in the Eifel; they are distinct from, though closely related to, those of the Carboniferous. In the Devonian, too, we find, side by side, forms of the Silurian Cystoidea and the Carboniferous Blastoidea.

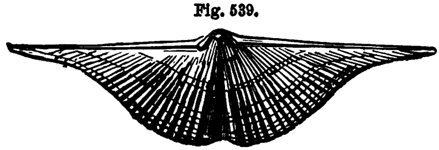
Among the Brachiopoda we find many forms of *Spirifera* (figs. 538, 539), *Productus*, *Orthis*, *Athyris*, *Atrypa*, *Chonetes*, &c., with certain genera peculiar to the Devonian system, such as *Stringocephalus* (fig. 540), *Uncites* (fig. 541), *Rensselæria*, *Meganteris*, &c.

Fig. 538.



Spirifera disjuncta, Sow., $\frac{1}{2}$.
Syn. *Sp. Verneuilii*, Murch.
Upper Devonian, Boulogne.

Fig. 539.



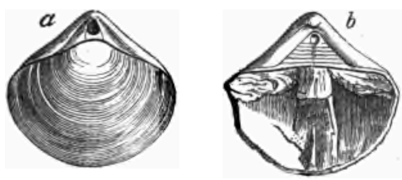
Spirifera mucronata, Hall, nat. size.
Devonian of Pennsylvania.

The Lamellibranchiata are represented by a number of genera, some of which are peculiar to the system. The genus *Megalodon* (fig. 542) is an abundant and characteristic one.

Gastropods of Mesozoic affinities, like *Pleurotomaria*, are

found mingled with forms like *Murchisonia*, which are abundant in the Older Palæozoic; while the Pteropoda, which are so abundant during the last-mentioned epoch, are represented in the Devonian by *Conularia* (fig. 543), *Tentaculites*, and other genera.

Fig. 540.

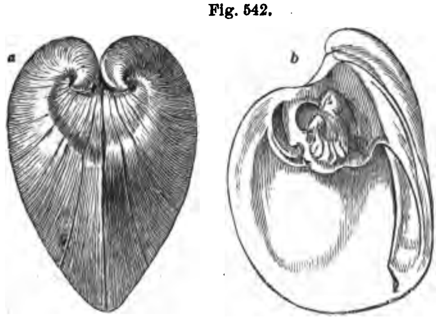


Stringocephalus Burtini, Def., $\frac{1}{2}$.
a. Valves united. *b.* Interior of ventral or large valve, showing thick partition and portion of a large process which projects from the dorsal valve across the shell.

Fig. 541.

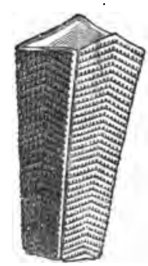
Uncites gryphus, Def., $\frac{2}{3}$.
Middle Devonian.
S. Devon and the Continent.

Fig. 542.



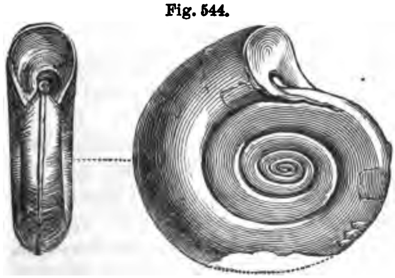
Megalodon cucullatus, Sow. Eifel; also Bradley, S. Devon.
a. The valves united.
b. Interior of valve, showing the large cardinal tooth.

Fig. 543.



Conularia ornata, D'Arch. and De Vern, $\frac{2}{3}$.
Refrath, near Cologne.

Fig. 544.



Clymenia linearis, Münst.
Petherwyn, Cornwall; Elbersreuth, Bavaria

Fig. 545.

Entomis serratostriata, Sandb. sp., Weilburg, &c.; Cornwall; Nassau; Saxony; Belgium.
a. Nat. size.

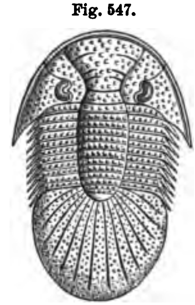
Among the Cephalopoda of the Devonian we find, side by side with the Older Palæozoic genera like *Orthoceras*, *Phragmoceras*, *Cyrtoceras*, &c., the oldest Ammonoidea in the *Goniatites*, and the remarkable and very characteristic genus *Clymenia* (fig. 544), which is confined to the Upper Devonian.

The Arthropoda of the Devonian include the Ostracod *Entomis* (fig. 545), the bivalve shells of which are found covering the surfaces of many of the shales. With the Eurypterids (usually found in the freshwater deposits of the period) we find a number of Trilobites, though these are no longer present in such numbers and variety as in the Older Palæozoic formations.

Fig. 546.

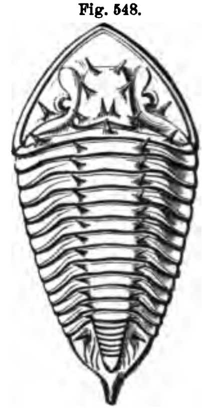
Phacops latifrons, Brönn, nat. size. Characteristic of the Devonian in Europe, Asia, and N. and S. America.

Fig. 547.



Bronteus flabellifer, Goldf. Mid. Devon; S. Devon; and the Eifel.

Fig. 548.



Homalonotus armatus, Burmeister, $\frac{1}{2}$. Lower Devonian; Daun, in the Eifel; and S. Devon.

Species of *Phacops* (fig. 546), *Bronteus* (fig. 547), and *Homalonotus* (fig. 548), often distinguished by an abundance of spines, tubercles, or other external ornaments, are particularly characteristic of the Devonian fauna.

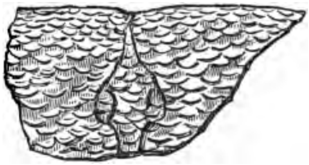
As already remarked, a few of the fish-remains so abundant in the freshwater deposits of this age are also found associated with the marine fossils of the Devonian.

The freshwater fauna of this period is a very interesting one, as it is the oldest known. It includes a representative of the Unionidæ (*Anodonta*, fig. 549), and a number of Crustaceans, including the Eurypterids *Pterygotus* (figs. 550, 551), *Eurypterus*, *Slimonia*, &c. The curious bodies known as *Parka decipiens*, Flem. (figs. 552–554), are believed to be egg-cases of some of these large Crustaceans.

Fig. 549.

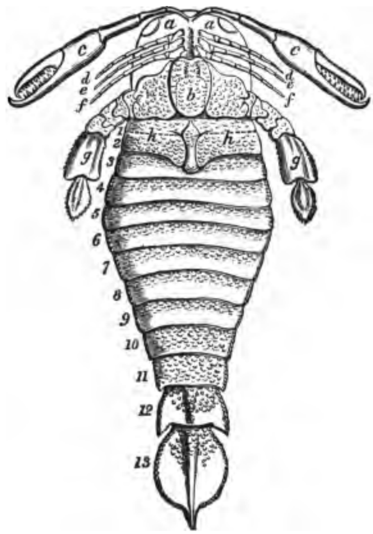
Anodonta Jukesii, Forbes, ½.
Upper Devonian, Kiltorkan, Ireland.

Fig. 550.



Pterygotus anglicus, Ag.
Middle portion of the back of the head, called the 'Seraphim.'

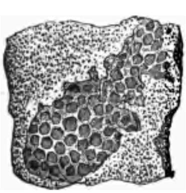
Fig. 551.



Pterygotus anglicus, Ag. Forfarshire. Ventral aspect. Restored by Dr. H. Woodward, F.R.S.

a. Carapace, showing the large sessile eyes at the anterior angles.
b. The *metastoma* or post-oral plate (serving the office of a lower lip).
c, *c*. Chelate appendages (*antennules*).
d. First pair of simple palpi (*antennæ*).
e. Second pair of simple palpi (*mandibles*).
f. Third pair of simple palpi (first *maxillæ*).
g. Pair of swimming feet with their broad basal joints, whose serrated edges serve the office of *maxillæ*.
h. Thoracic plate covering the first two thoracic segments, which are indicated by the figures 1, 2, and a dotted line.
1–6. Thoracic segments.
7–12. Abdominal segments.
13. Telson, or tail-plate.

Fig. 552.



Parka decipiens, Flem.
In sandstone of lower beds of Old Red, Ley's Mill, Forfarshire.

Fig. 553.

Parka decipiens, Flem., nat. size.
In shale of Lower Old Red, Park Hill, Fife.

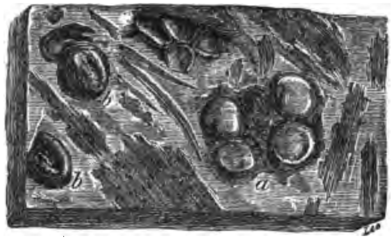


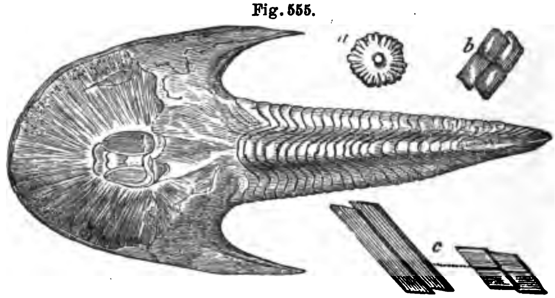
Fig. 554.

Old Red Sandstone Shale of Forfarshire. With impression of plants and ova of Crustaceans. Nat. size.

a. Two pairs of ova (?) resembling those of large Salamanders or Tritons—on the same leaf.
b, *b*. Detached ova.

Most interesting of all are the remains of fishes found in these freshwater strata of Devonian age. In addition to a few representatives of the Rays, we find very remarkable forms of heterocercal ganoids, in such forms as *Cephalaspis* (figs. 555, 556), *Pteraspis*, &c.

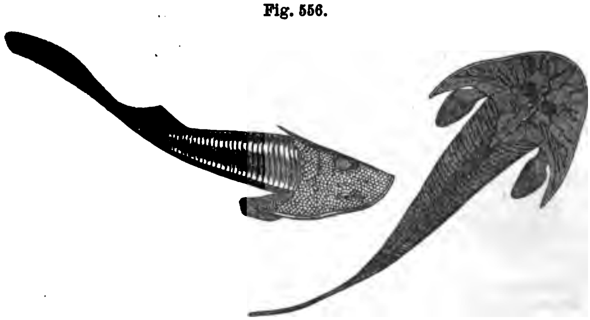
Fig. 555.



Cephalaspis Lyellii, Ag. Length 6½ inches.
From a specimen found at Glamis, in Forfarshire.
(See other figures, Agassiz, vol. ii. table 1 *a* and 1 *b*.)

a. One of the peculiar scales with which the head is covered when perfect. These scales are generally removed, as in the specimen above figured.
b, *c*. Scales from different parts of the body and tail.

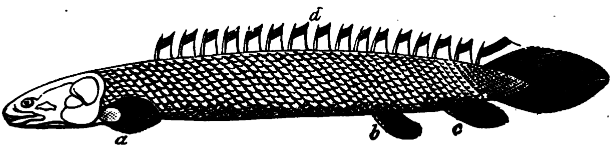
Fig. 556.



Cephalaspis Lyellii, Ag. Restoration. (After Page.)

By far the greater number of the Old Red Sandstone fishes belong to the suborder of Ganoids, called *Crossopterygidæ* or fringe-finned, by Huxley in 1861, in consideration of the peculiar manner in which the fin-rays of the paired fins are

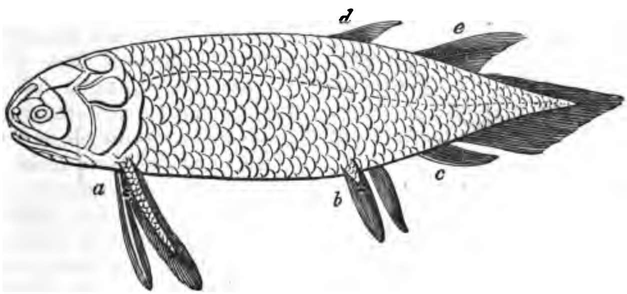
Fig. 557.



Polypterus. Living in the Nile and other African rivers.

a. One of the fringed pectoral fins.
b. One of the ventral fins.
c. Anal fin.
d. Dorsal fin, or row of finlets.

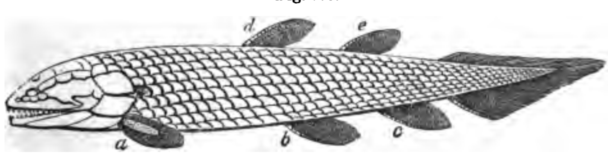
Fig. 558.



Holoptychius. As restored by Professor Huxley.

a. The fringed pectoral fins.
b. The fringed ventral fins.
c. Anal fin.
d, e. Dorsal fins.

Fig. 559.



Restoration of *Osteolepis.* Pander. Old Red Sandstone, or Devonian.

a. One of the fringed pectoral fins.
b. One of the ventral fins.
c. Anal fins.
d, e. Dorsal fins.

arranged so as to form a fringe round a central lobe, as in the recent *Polypterus* (see *a*, fig. 557), a genus of which there are several species now inhabiting the Nile and other African rivers. The reader will at once recognise in *Osteolepis* (fig. 559), one of the common fishes of the Old Red Sandstone, many points of

analogy with *Polypterus*. They not only agree in the structure of the fin, as first pointed out by Huxley, but also in the position of the pectoral, ventral, and anal fins, and in having an elongated body and rhomboidal scales. On the other hand, the tail is more symmetrical in the recent fish, which has also an apparatus of dorsal finlets of a very abnormal character, both as to number and structure. As to the dorsals of *Osteolepis*, they are two in number, which is unusual in living fish.

Fig. 560.

Scale of *Holoptychius nobilissimus*, Ag. Clashbinnie, ½ nat. size.

Among the 'fringe-finned' Ganoids we find some with rhomboidal scales, such as *Osteolepis*, figured above; others with cycloidal scales, as *Holoptychius* (figs. 558, 560). In the genera *Dipterus* and *Diplopterus*, as Hugh Miller pointed out, and in several others of the fringe-finned genera, as in *Gyroptychius* and *Glyptolepis*, the two dorsals are placed far backwards, or directly over the ventral and anal fins. The *Asterolepis* (one of the Placodermata) was a ganoid fish of large dimensions. *A. Asmusii*, Eichwald, a species characteristic of the Old Red Sandstone (Devonian) of Russia, as well as of the same rocks in Scotland, attained, according to Hugh Miller, the length of between twenty and thirty feet. They were partly clothed with strong bony armour, embossed with starlike tubercles. *Asterolepis* occurs also in the Devonian rocks of North America.

Fig. 561.

Pterichthys, Agassiz; upper side, showing mouth; as restored by H. Miller.

Amongst the interesting points which have been recorded about the ganoid fish, Professor Huxley has observed that, while a few of the Palæozoic and the majority of the Secondary Ganoids resemble the living Bony Pike (*Lepidosteus*), or the *Amia*, genera now found in North- and Central-American rivers, the Crossopterygidæ of the Old Red are closely related to the African *Polypterus* of the Nile and the rivers of Senegal. In 1870, a species of another genus of the

Crossopterygidæ, *Ceratodus Forsteri*, Krefft, was found living in the rivers of Queensland, Australia.

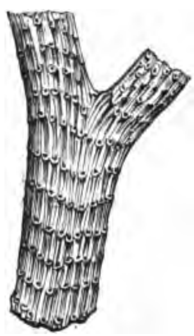
If many circumstances favour the theory of the freshwater origin of the Old Red Sandstone, this view of its nature is not a little confirmed by our finding that it is in Lake Superior and the other inland Canadian freshwater seas, and in the Mississippi and African rivers, that we at present find those fish which have the nearest affinity to the fossil forms of this ancient formation.

The peculiar family of Crossopterygidæ—of which we have a living example in the *Polypterus* of the Nile—had many

Fig. 562.

Palæopteris hibernica, Schimp. (*Cyclopteris hibernica*, Ed. Forbes.) (*Adiantites*, Göpp.) Upper Devonian, Kilkenny.

Fig. 563.



Bifurcating branch of *Lepidodendron Griffithsii*, Brong. Upper Devonian, Kilkenny.

representatives in Devonian times, including such representative genera as *Holoptychius* (fig. 558), *Osteolepis* (fig. 559), *Glyptolepis*, &c.

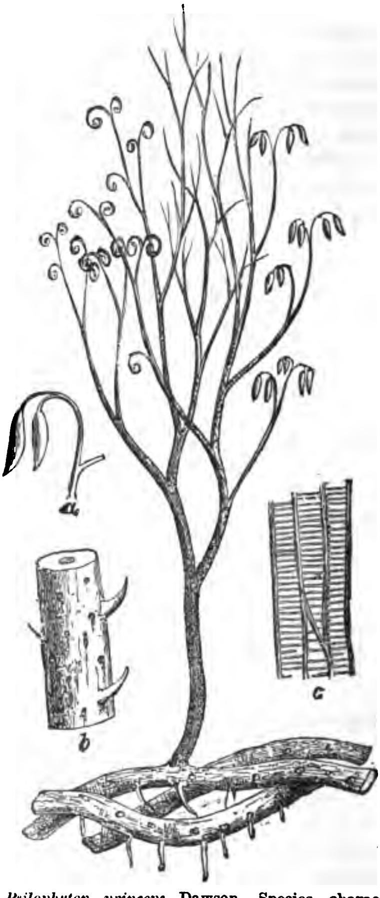
Among the anomalous forms of Old Red fishes not referable to Huxley's Crossopterygidæ, and which are even doubtful Ganoids, having many structures which relate them to modern Siluroids amongst the Teleosteans, are the genera *Pterichthys*, *Cephalaspis*, *Pteraspis*, and *Coccosteus*. With regard to *Pterichthys*, some writers have compared its shelly covering to that of Crustaceans, with which, however, it has no real affinity. The wing-like appendages, whence the genus is named, were first supposed by Hugh Miller to be paddles, like those of the turtle; and there can now be no doubt that they do really correspond with the pectoral fins (fig. 561).

The genus *Cephalaspis*, or 'buckler-headed,' from the extraordinary shield which covers the head (figs. 555, 556), has the orbits close together, nearly in the centre of the shield, which has a horn on either side carried backwards. *Pteraspis*, of the same family, has also been found by the Rev. Hugh Mitchell in Old Red beds, Perthshire; and it is interesting to note that this genus came in during late Silurian times. Mr. Powrie enumerated no less than five genera of the suborder Acanthodidæ, the spines, scales, and other remains of which have been detected in the grey flaggy sandstones, the chief genera being *Acanthodes*, *Diplacanthus*, and *Cheiracanthus*.

Fig. 564.

Cone and branch of *Lepidodendron corrugatum*. Lower Carboniferous, New Brunswick.

Fig. 565.



Psilophyton princeps, Dawson. Species characteristic of the whole Devonian series in North America.
a. Fruit, natural size. *b*. Stem, natural size.
c. Scalariform tissue of the axis, highly magnified.

In the Old Red Sandstone of Caithness Dr. R. H. Traquair has discovered the remains of a minute fish of very rudimentary

organisation, which appears to have curious affinities with the Lamprey and Hag, and to be referable to the group of the Marsipobranchia. He has called this curious, ancient and rudimentary type of fish *Palæospondylus Gunni.*

While the Dipnoi are represented by *Dipterus*, the forerunner of the genus *Ceratodus*, which lived on from the earliest Mesozoic to the present day, vertebrates of higher organisation than fishes have not as yet been met with in Devonian strata.

The terrestrial flora of Devonian times does not appear to have differed in its general characters from that of the Carboniferous period. Gigantic ferns like *Palæopteris* (fig. 562), with true Lepidodendrids (figs. 563, 564), are found mingled with some peculiar types like the *Psilophyton* of Sir J. W. Dawson, the affinities of which are somewhat doubtful (fig. 565). The form is interesting on account of its great antiquity.

The flora of the Old Red Sandstone is poor, but extremely interesting from its foreshadowing the later grand Carboniferous flora.

In the Upper Old Red there are only twelve species of plants, and the following genera are represented :—*Adiantites*, *Calamites*, *Filicites*, *Sagenaria*, *Sphenopteris*, *Trichomanites*, and *Knorria.* The Lower Division contains *Lepidodendron*, also a Coniferous plant, and *Psilophyton.*

The earliest known insects were brought to light in 1865 in the Devonian strata of St. John's, New Brunswick, and are referred by Mr. Scudder to the group *Pseudo-neuroptera.* One of them, a *Platephemera*, measured five inches in expanse of wing. It was an ancient May Fly with some peculiar structures not found in living representatives of the group.

The genus *Xenoneura* has a remarkable union of characters which are found in different genera at the present day. It is a lace-winged form of the May-fly group, furnished with a stridulating or musical organ like a Grasshopper. Such a genus is said to constitute a synthetic type.

British representatives of the Devonian system.—Marine strata of Devonian age are only found in the British Isles in Devonshire and Cornwall. The rocks are much folded, faulted and altered: and, except in certain limestone beds, fossils are few and badly preserved in them. By a comparison of the fossils of the Devonshire strata with those of the richly fossiliferous beds of the Eifel, Mr. Ussher has been able to make out the following succession in South Devon, which may be placed in general parallelism with the divisions recognised in North Devon.

	South Devon	North Devon
Upper Devonian	Cypridina (Entomis) shales Goniatite limestone and shales	Pickwell Down sandstones (without fossils)
Middle Devonian	Middle Devonian limestones, *Stringocephalus* limestone (Ashprington Volcanic series) Eifelian shales and shaly limestones, with *Calceola sandalina*, Lam.	Morte slates (without fossils) Ilfracombe beds (with *Stringocephalus* limestone)
Lower Devonian	Grits and sandstones, with *Homalonotus*, *Pleurodictyum*, &c.	Hangman Grits and Foreland sandstones. Lynton slates

In North Devonshire the unfossiliferous Pickwell Down sandstones are overlain by the Baggy, Marwood and Pilton beds, but these are now generally regarded either as Carboniferous in age or as constituting a transition series between the Devonian and Carboniferous. Similar strata intermediate in age between the Devonian and Carboniferous are found in Ireland, and are known as the Carboniferous slate and the Kiltorcan beds.

Upper Devonian Rocks.—The slates and sandstones of Barnstaple contain the Brachiopod *Spirifera disjuncta*, Sow. (fig. 538), which has a very wide range in Europe, Asia Minor, and even China; also *Strophalosia caperata*, Sow., together with the large Trilobite, *Phacops latifrons*, Bronn (fig. 546), which is all but world-wide in its distribution. The fossils are numerous, and comprise about 150 species of mollusca, a fifth of which pass up into the overlying Carboniferous rocks. To this Upper Devonian belong a series of limestones and slates well developed at Petherwyn, in Cornwall, where they have yielded 75 species of fossils. The genus of Cephalopoda called *Clymenia* (fig. 544) is represented by no less than 11 species, and strata occupying the same position in Germany are called Clymenien-Kalk, or sometimes Cypridinen-Schiefer, on account of the number of minute bivalve shells of the Crustacea called *Entomis* (*Cypridina*) *serratostriata*, Sandb. (fig. 545), which is found in these beds in the Rhenish provinces, the Harz, Saxony, and Silesia, as well as in Cornwall and Belgium.

Middle Devonian Rocks. We come next to the most typical portion of the Devonian system, including the great limestones of Plymouth and Torquay, as well as the slates and impure limestones of Ilfracombe, all replete with shells, trilobites, and corals. Of the corals 52 species are enumerated by Mr. Etheridge, none of which pass into the Carboniferous formation above or came from the Silurian strata below, although many genera are common to the three systems. Among the genera are *Favosites*, *Heliolites*, *Smithia*, *Heliophyllum*, and *Cyathophyllum*. The *Heliophyllum Halli*, E. and H., a Rugose Coral (fig. 535), and *Heliolites porosa*, Goldf., an Alcyonarian (fig. 536), are species peculiar to this formation.

Stromatopora occurs, and a few Bryozoa. With the above are found no less than 10 genera of Echinodermata, 6 of which are stone-lilies or Crinoids; some of them, such as *Cupressocrinus*, are distinct from any Carboniferous forms. The mollusca also are less characteristic; of 26 genera of Brachiopoda, 19 are common to the Carboniferous series. The *Stringo-*

cephalus Burtini, Defr. (fig. 540), and *Uncites gryphus*, Defr. (fig. 541), may be mentioned as exclusively Middle-Devonian genera, and extremely characteristic of the same division in Belgium. The *Stringocephalus* is also so abundant in the Middle Devonian of the banks of the Rhine as to have suggested the name of Stringocephalus-Limestone. The only two species of Brachiopoda common to the Silurian and Devonian formations are *Atrypa reticularis*, L., which seems to have been a cosmopolitan species, and *Strophomena rhomboidalis*, Wilc.

Among the Lamellibranchiate bivalves common to the Plymouth limestone of Devonshire and the Continent, we find the *Megalodon* (fig. 542). There are also 18 genera of Gastropoda, which have yielded 45 species, 5 of which pass to the Carboniferous group, namely, *Acroculia vetusta*, *Loxonema rugifera*, Phil., *L. tumida*, Phil., *Murchisonia angulata*, Phil., and *M. spinosa*, Phil. The Pteropod *Tentaculites* occurs in England, and on the Continent is found the genus *Conularia* (fig. 548). The Cephalopods have species of *Cyrtoceras*, *Goniatites*, *Orthoceras*, *Nautilus*, and nearly all of them are distinct from those in the Upper Devonian Limestone, or Clymenien-Kalk of the Germans, already mentioned. Although but 6 species of Trilobites occur, the characteristic *Bronteus flabellifer*, Goldf. (fig. 547), is far from rare, and all collectors are familiar with its fanlike tail. In this same group, called, as before stated, the Stringocephalus or Eifel Limestone in Germany, several fish-remains have been detected, and among others the remarkable Old Red genus *Coccosteus*, covered with its tuberculated bony armour; and these ichthyolites serve, as Sir R. Murchison pointed out, to identify this middle marine Devonian with the Old Red Sandstone of Britain and Russia.

Beneath the Eifel Limestone (the great central and typical member of the Devonian on the Continent) lie certain schists called by German writers 'Calceola-Schiefer,' containing in abundance *Calceola sandalina*, Lam. (fig. 537), which was once considered a Brachiopod, but which has been shown to be an operculate coral. This is by no means a rare fossil in the slaty limestone of South Devon, and, as in the Eifel, is confined to the middle division of the system.

Lower Devonian Rocks.—A great series of sandstones and glossy slates, with Crinoidea, Brachiopoda, and some corals and Bryozoa, occurring on the coast at Lynmouth and the neighbourhood, and called the Lynton Group, form the lowest member of the Devonian in North Devon. Traces of fish-remains occur, and *Pteraspis*, a genus of Silurian fish, has been detected. Among the 18 species of all classes enumerated by Mr. Etheridge, two-thirds are common to the Middle Devonian; but only one, the ubiquitous Brachiopod *Atrypa reticularis*, L., can be identified with Silurian species. Among the characteristic forms are *Alveolites suborbicularis*, Lam., also common to this formation on the Rhine, and *Orthis arcuata*, Phil., very widely spread in the North Devon localities. But we may expect a large addition to the number of fossils whenever these strata shall have been carefully searched. The Spirifer-sandstone of Sandberger, as exhibited in the rocks bordering the Rhine between Coblentz and Caub, belong to this lower division, and the same broad-winged Spirifers distinguish the Devonian strata of North America.

Among the Trilobites of this era are the genera *Phacops* (fig. 546), and several large species of *Homalonotus* (fig. 548) are conspicuous. The genus is still better known as a Silurian form, but the spinose species appear to belong exclusively to the 'Lower Devonian,' and are found in Britain, Europe, and the Cape of Good Hope.

Old Red Sandstone.—Over the greater part of the British Islands we find developed the freshwater facies of the Devonian, which is known as the Old Red Sandstone. In South Wales and Hereford we find a great thickness (10,000 feet) of red and green shales, flagstones, sandstones, and conglomerates, with some impure concretionary limestones; these pass downwards conformably into the Silurian and upwards into the Carboniferous. In the transition beds a few marine fossils are found mingled with freshwater forms; but in the great mass of the strata of this age only fishes and a few traces of land plants have been found. In Scotland, the Old Red Sandstone can be separated into three subdivisions, each of which contains a characteristic fish-fauna. The Upper Old Red Sandstone, which is found both in Fife and the Orkney Islands, and consists of yellow and red sandstone, contains many forms of *Holoptychius*, *Pterichthys*, *Glyptopomus*, *Glyptolæmus*, &c., and appears to graduate upwards into the Carboniferous. In Caithness a great series of flagstones, alternating with variegated sandstones, contains a very rich fauna including *Cheiracanthus*, *Cheirolepis*, *Dipterus*, *Diplacanthus*, &c., with many remarkable examples of the small phyllopod *Estheria minuta*, Goldf., and some plant remains: these are regarded by many geologists as constituting a distinct subdivision, the Middle Old Red Sandstone. The Lower Old Red Sandstone, which contains many forms of Cephalaspid fish and Eurypterids and appears to graduate downward into the Silurian, is well developed in Perthshire and Forfarshire. The Scottish strata of Old Red Sandstone age are of enormous thickness, and include many masses of very coarse conglomerate, which by some authors have been thought to be of glacial origin. That the Old Red Sandstone was of freshwater origin there can be little doubt, and some geologists have even attempted to define the limits of the great freshwater lakes in which its beds were laid down.

The Old Red Sandstone of Scotland.—Murchison divided the Old Red Sandstone into three groups, which he supposed were more or less contemporaneous with the three divisions of the Marine Devonian. But Sir A. Geikie regards the Old Red Sandstone as constituting only two divisions. He considers the Old Red Sandstone to have been deposited in separate basins or lakes, which were five in number. 1. Lake Orcadie, north of the Grampian range, and including the Orkneys. 2. Lake Caledonia, occupying the central valley of Scotland between the Highlands to the north and the Silurian uplands to the south. It probably was prolonged across the Firth of Clyde into the north of Ireland. 3. Lake Cheviot, in the south-east of Scotland and north of England. 4. The Welsh Lake, bounded by the Silurian hills to the north and west. 5. Lake Lorne, a district in the north of Argyllshire, on the flanks of the South-west Highlands. The twofold division of the Old Red is seen, according to this author, typically in Lake Caledonia. The Upper Old Red, as he shows, merges gradually into the Lower Carboniferous strata above, and the Lower Old Red passes conformably into the Silurian formation below; but there is complete unconformity between the two series. He further notices the occurrence in Lanarkshire of Silurian fossils—a Graptolite, *Spirorbis Lewisii*, Sow., and *Orthoceras dimidiatum*, Sow.—about 5,000 feet above the base of the Old Red. He states: 'This interesting fact serves to indicate that though geographical changes had elevated the Upper Silurian sea-floor, partly into land and partly into inland water-basins, the sea outside still contained

an Upper Silurian fauna, which was ready on any favourable opportunity to re-enter the tracts from which it had been excluded.

The Middle and Lower Old Red Sandstones attain a depth of deposits in the central district of Scotland of 20,000 feet, and the strata present, everywhere, evidences of shallow-water conditions. There are proofs that local elevation occurred during the ages of general subsidence, which enabled the deposits to accumulate. In Lanarkshire the strata rest on Silurian rocks conformably, but on others unconformably. The strata, which are red, brown, chocolate-coloured, grey, and yellow, include sandstones, shales, flags, coarse conglomerates, and occasional cornstones and limestones. The grey flags and thin grey and olive shales and 'calm-stones' are almost confined to Forfarshire, and in the north-east part of the basin are known as Arbroath flags. One of the most marked features is the occurrence of prodigious masses of interbedded volcanic rocks having a thickness of more than 6,000 feet in this central basin. As a rule, the deposits of this area are singularly unfossiliferous, though the Arbroath flags have been proved to be rich in the remains of fish and crustacea. In Forfarshire and Perthshire plant-remains are found.

The Old Red Sandstone of the northern area contains the dark grey, bituminous schists and flagstones whose fossil fish were so well described by Hugh Miller, and the calcareous flagstones of Caithness, resting on red sandstones and conglomerates. These last repose upon the up-tilted Silurian rocks.

Upper Old Red Sandstone.—The highest beds of the series in Scotland, lying immediately below the Carboniferous formation, consist of yellow and red sandstones and conglomerates, well seen at Dura Den, near Cupar, in Fife, where, although the strata contain no mollusca, fish have been found abundantly, and have been referred to *Holoptychius nobilissimus*, Ag., *H. Andersoni*, Ag., *Pterichthys major*, Ag., and to species of *Glyptopomus* and other genera.

The number of individuals of species at Dura Den, crowded profusely through the pale sandstone, indicates, according to Sir A. Geikie, that the fish were killed suddenly and covered with sediment rapidly.

Sir R. Murchison groups with this upper division of the Old Red of Scotland certain light-red and yellow sandstones and grits which occur in the northernmost part of the mainland and extend also into the Orkney and Shetland Islands. They contain *Calamites* and other plants which agree, generically, with Carboniferous forms, and overlie the Caithness flags unconformably. The Fish fauna of the Upper Old Red Sandstone numbers 25 species belonging to 15 genera.

Sir A. Geikie notices that a band of marine limestone of Devonian age, lying in the heart of the Old Red in Arran, is crowded with ordinary Carboniferous Limestone shells, such as *Productus giganteus*, Mart. sp., *P. semireticulatus*, Mart. sp.; but none occur in the great series of sandstones overlying the limestone. These species do not reappear until we reach the limestones of the Carboniferous age, yet all these organisms must have been living before the deposition of the Arran limestone, and, of course, long prior to the formation of the Carboniferous limestone.

Across the border districts, the sandstones and conglomerates of the Upper Old Red rest unconformably on Silurian rocks; and Old Red Sandstone with breccias and conglomerates appears under the Carboniferous formation along the flanks of the Cumberland and Westmoreland Hills, and in corresponding succession as far south as Flintshire and Anglesea.

The Fish-remains, which have made the Old Red Sandstone so interesting, belong mainly, but not entirely, to the middle and lower divisions. While the Upper Old Red has 25 species, the Middle and Lower Old Red contain 85 species distributed among 36 genera. In this portion of the series there are

12 species of Placoid fish, and all the rest belong to the Ganoids. In explanation of this statement, it may be said that Agassiz divided the Devonian fish into two great orders, namely, the Placoids and Ganoids. Of the first of these, which at the present time comprises the cartilaginous fish, like the Shark, the Dog-fish, and the Ray, no skeletons are preserved; but fin-spines, called Ichthyodorulites, and teeth occur. On such remains the genera *Onchus*, *Homacanthus*, *Ctenacanthus*, and *Cosmacanthus*, with many others occurring in the Old Red Sandstone, have been established.

The Old Red Sandstone of Southern Britain.—The grandest exhibitions, says Sir R. Murchison, of the Old Red Sandstone in England and Wales appear in the escarpments of the Black Mountains and in the Vans of Brecon and Caermarthen, the one 2,862, and the other 2,590 feet above the sea. The mass of red and brown sandstone in these mountains is estimated at not less than 10,000 feet, clearly intercalated between the Carboniferous and Silurian strata. No shells or corals have ever been found in the whole series, not even where the beds are calcareous, forming irregular courses of concretionary lumps called 'cornstones,' which may be described as mottled, red and green, earthy limestones. The fishes of this lowest English Old Red are *Cephalaspis* and *Pteraspis*, specifically different from representatives of the same genera which occur in the uppermost Ludlow (Silurian) tilestones. Crustaceans also of the genus *Eurypterus* are met with.

Besides the bodies called *Parka decipiens*, Flem. (figs. 532–534, p. 379), there are found the spore-cases or floats of a lowly organised plant called *Pachytheca*.

The Old Red Sandstone of Ireland.—In Ireland, as in Scotland, the upper division of the Old Red Sandstone lies unconformably upon the lower, and in South Wales the upper beds overlap the lower strata, 'indicating,' wrote Sir A. Ramsay, 'great disturbance and denudation,' but not presenting any insuperable difficulty as to the freshwater origin of the strata.

A dearth of calcareous matter over wide areas is characteristic of the Old Red Sandstone. This is, no doubt, in great part due to the absence of marine deposits and the scarcity of freshwater animals with calcareous shells.

In the county of Cork, in Ireland, a similar yellow sandstone occurs containing fish of genera characteristic of the Scotch Old Red Sandstone, as, for example, *Coccosteus* (a form represented by many species in the Old Red Sandstone and by one only in the Carboniferous group) and *Glyptolepis*, which is exclusively confined to the 'Old Red.' In the same Irish sandstone at Kiltorcan has been found an *Anodonta* or freshwater mussel, the only shell hitherto discovered in the Old Red Sand-

stone of the British Isles (see fig. 549). In the same beds are found the Fern (fig. 562) and the *Lepidodendron* (fig. 563), and twelve other species of plants, some of which agree specifically with species from the Lower Carboniferous beds. This fact lends some support to the opinion, long ago advocated by Sir Richard Griffith, that the yellow sandstone, in spite of its fish-remains, should be classed as Lower Carboniferous—an opinion which is not generally adopted by geologists. Between the Mountain Limestone and the yellow sandstone in the South-west of Ireland, there intervenes a formation no less than 5,000 feet thick, called the 'Carboniferous slate;' and at the base of this, in some places, are local deposits, such as the Coomhola Grits, which appear to be beds of passage between the Carboniferous and Old Red Sandstone groups.

The most trustworthy account of the Devonian strata of Devonshire and Cornwall is contained in the papers of Mr. Ussher, of the Geological Survey. Very interesting descriptions of the Old Red Sandstone of Scotland and its fossils are to be found in the writings of the late Hugh Miller, and also in the works of Sir A. Geikie.

CHAPTER XXIII

FOREIGN DEPOSITS WHICH ARE HOMOTAXIAL WITH THE NEWER PALÆOZOIC STRATA OF THE BRITISH ISLES

The Devonian rocks of the Eifel—of the Ardennes and Brittany—of the Carinthian Alps, the Iberian peninsula, and Russia—Carboniferous strata of France, Germany, and Russia—Permian strata of Central Germany, the Alps, and the Ural Mountains—Devonian strata of the United States, Canada, and the Arctic Regions—Carboniferous strata of the United States—Permian strata of Texas and Nebraska—Devonian, Carboniferous, and Permian of India and Australia.

NEWER PALÆOZOIC ROCKS OF EUROPE

Devonian strata of the Eifel district.—The Oldest of the Newer Palæozoic strata, the Devonian or Eifelian, find their fullest representation in the district of Rhenish Prussia, where limestones and other strata abounding with beautiful, well-preserved fossils occur.

The general classification adopted for these strata is as follows:—

Upper Eifelian { Clymenia Limestone and Cypridina (Entomis) Shales.
Goniatite Limestone.

Middle Eifelian	Stringocephalus beds.
	Calceola beds.
	Zone of *Spirifera cultrijugata*, Röm.
Lower Eifelian	Coblenz Slates and Quartzite (Spirifer Sandstones).
	Hunsrück Slates.
	Sericitic Slates of the Taunus.

The Upper and Middle Eifelian are composed of limestones with beds of shale, the strata yielding a great number of fossils. The Lower Eifelian consist of rocks, in places much altered, which attain a thickness of 10,000 feet; these rocks being chiefly quartzites, felspathic sandstones (greywackés), and phyllites that sometimes assume almost a gneissic aspect.

Devonian of other parts of Western Europe.—In the Ardennes to the west, and in Thuringia, the Harz, and Bohemia to the east, the Devonian strata are exhibited with divisions that can be approximately paralleled with those of the Eifel. The Devonian strata also appear in Brittany. The French geologists usually classify the Devonian in the following groups:

Upper Devonian	Famenian
	Frasnian
Middle Devonian	Givetian
	Eifelian
Lower Devonian	Coblenzian
	Taunusian
	Gedinnian

In the Carinthian Alps, strata of Lower, Middle, and Upper Devonian age lie conformably upon the Upper Silurian rocks, and in Southern France, and in Spain and Portugal, slates, limestones, and sandstones of this age have been long known, and the formation as displayed in Asturias has now been fully described by M. Barrois.

Devonian of Russia.—The Devonian strata of Russia extend, according to Sir R. Murchison, over a region more spacious than the British Isles; and it is remarkable that, where they consist of sandstone like the 'Old Red' of Scotland and Central England, they are tenanted by fossil fishes often of the same species and still oftener of the same genera as the British, whereas when they consist of limestone they contain shells similar to those of Devonshire, thus confirming, as Sir Roderick has pointed out, the contemporaneous origin which had been previously assigned to formations exhibiting two very distinct mineral types in different parts of Britain. The calcareous and the arenaceous rocks of Russia, above alluded to, alternate in such a manner as to leave no doubt of their having been deposited in different parts of the same great period.

While in North-Western and Central Russia we find these alternations of the marine (Devonian) and of the freshwater (Old Red Sandstone) types, in the Ural district there is a completely marine series similar to that of the Eifel, but exhibiting many interesting differences in the order of succession of the beds and in the species of organisms present in them.

Carboniferous strata of Europe.—The divisions of the Carboniferous rocks of France and Germany can be generally paralleled with those of this country. In Germany, as in the South-West of England (Devonshire), we sometimes find the richly coal-bearing beds replaced by masses of barren measures (the 'Culm facies' of the Carboniferous rocks). When we pass to Russia, however, we find the marine facies (Fusulina limestones, &c.) forming the upper member of the series, and the productive Coal-measures below them, while in this country, as we have seen, the opposite is the case.

The general succession of the Carboniferous strata in Russia is as follows:—

Upper Carboniferous	Limestones with Fusulina.
	Stage of *Spirifera mosquensis*, Fisch., at base.
Lower Carboniferous	Limestones with *Productus giganteus*, L.
	Productive coal-bearing strata.
	Stage of *Productus mesolobus*, Phil., at base.

Permian Strata of Europe. The main features of the British Permian are reproduced in Central Germany. There the upper member (the Zechstein) attains a considerable thickness, and in Thuringia it includes the Kupferschiefer, a bed containing fishes and other fossils mineralised by copper pyrites. This stratum was formerly largely worked as a copper ore. The Zechstein rests unconformably on the Rothliegende, and has a much more restricted development than the latter formation. In France, the Permian is only represented by its lower member.

In the Alpine district and in Sicily, however, we find the marine type of the Permian well exhibited in the Bellerophon and Fusulina limestones. The same fauna is found in beds on the western slopes of the Ural Mountains (Artinsk stage of Karpinsky), and stretching through Asia Minor into Northern India.

NEWER PALÆOZOIC STRATA OF AMERICA

In the United States strata of Newer Palæozoic age attain a grand development, but it is by no means easy to correlate the various divisions of this great mass of strata with the European Permian, Carboniferous, and Devonian systems respectively. A number of very distinct life-provinces are now recognised in this area—the Acadian (including New England and the Eastern part of British America), the Appalachian, the Mississippian, and the Michigan. In these several life-provinces—while a general parallelism can be detected between the fossils of the successive divisions and those of the great divisions of the European Carboniferous—there are a large number of species peculiar to the American continent, not a few which are restricted to one or other of these particular areas. In the western territories of North America, the Carboniferous strata resemble those of Russia and Eastern Asia, rather than those of Western Europe.

Devonian strata in the United States and Canada. Between the Carboniferous and the Silurian strata in the United States and Canada, there intervenes a great series of formations referable to the Devonian group, comprising some marine strata abounding in shells and corals, and others of shallow-water and littoral origin, in which terrestrial plants abound. The fossils, both of the deep and shallow-water strata, are very analogous to those of Europe, the species being in some cases the same. In Eastern Canada Sir W. Logan has pointed out that in the peninsula of Gaspé, south of the estuary of the St. Lawrence, a mass of sandstone, conglomerate, and shale referable to this period occurs, rich in vegetable remains, together with some fish-spines. Far down in the sandstones of Gaspé Dr. Dawson found in 1869 an entire specimen of the genus *Cephalaspis*, a form very characteristic, as we have already seen, of the Scotch Lower Old Red Sandstone. Some of the sandstones are ripple-marked; and towards the upper part of the whole series a thin seam of coal has been observed, measuring, together with some associated carbonaceous shale, about three inches in thickness. It rests on an underclay in which are

the roots of *Psilophyton* (see fig. 565). At many other levels rootlets of this same plant have been shown, by Principal Dawson, to penetrate the clays, and to play the same part as the rootlets of *Stigmaria* in the coal formation.

We had already learnt from the works of Göppert, Unger, and Bronn, that the European plants of the Devonian epoch resemble generically, with few exceptions, those already known as Carboniferous; and Dr. Dawson, in 1859, enumerated 32 genera and 69 species which he had then obtained from the State of New York and Canada. A perusal of his catalogue, comprising *Coniferæ*, *Sigillariæ*, *Calamites*, *Asterophyllites*, *Lepidodendra*, and ferns of the genera *Cyclopteris*, *Neuropteris*, *Sphenopteris*, and others, together with fruits, such as *Cardiocarpon* and *Trigonocarpon*, might dispose geologists to believe that they were presented with a list of Carboniferous fossils, the difference of the species from those of the Coal-measures, and even a slight admixture of genera unknown in Europe, being naturally ascribed to geographical distribution and the distance of the New from the Old World. But fortunately the Coal formation is fully developed on the other side of the Atlantic, and is singularly like that of Europe, both lithologically and in the species of its fossil plants. There is also the most unequivocal evidence of relative age afforded by superposition, for the Devonian strata in the United States are seen to crop out from beneath the Carboniferous on the borders of Pennsylvania and New York, where both formations are of great thickness.

The number of American Devonian plants has now been raised by Dr. Dawson and others to 160, to which we may add about 80 from the European flora of the same age, so that already the vegetation of this period is beginning to be nearly half as rich as that of the Coal-measures which have been studied for so much longer a time and over so much wider an area. The *Psilophyton*, above alluded to, is very widely distributed in Canada. Its remains have been traced through all the members of the Devonian series in America, and Dr Dawson has lately recognised it in specimens of Old Red Sandstone from the North of Scotland.

Fig. 566.

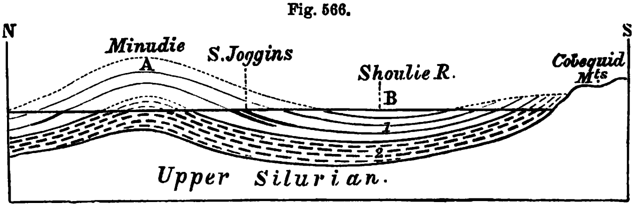


Diagram showing the curvature and supposed denudation of the Carboniferous strata in Nova Scotia.
A. Anticlinal axis of Minudie. B. Synclinal of Shoulie River.
1. Coal-measures. 2. Lower Carboniferous.

It is a remarkable result of the recent examination of the fossil flora of Bear Island, lat. 74° 30′ N., that Professor Heer has described as occurring in that part of the Arctic region (nearly twenty-six degrees to the north of the Irish locality) a flora agreeing in several of its species with that of the yellow sandstones of Ireland. This Bear Island flora is believed by Professor Heer to comprise species of plants some of which ascend even to the higher stages of the European Carboniferous formation, or as high as the Mountain Limestone and Millstone Grit. Palæontologists have long maintained that the same species which have a wide range in space are also the most persistent in time, which may

CORRELATION OF THE NEWER PALÆOZOIC STRATA OF DIFFERENT AREAS

—	—	British Isles	Central Europe	Russia	North America
PERMIAN (DYAS)	Thuringian	Magnesian limestone Marl slate	Gypsum and anhydrites Zechstein limestone Copper slates	Clays, marls, and gypsum Cephalopod beds —	Limestones and schists of Kansas with gypsum Cephalopod schists of Texas
	Saxonian	Sandstones and clays	Roth-todt-liegende	Copper-bearing sandstones	Sandstones and schists of Nebraska
	Autunian (Arkinskian)	— —	— —	Limestone and dolomites Sandstones of Artinsk	Fusulina beds Upper barren Coal-measures
CARBONIFEROUS	Ouralian or Stephanian	Upper Coal-measures —	Coal-measures —	Fusulina limestone Fusulina dolomites	Upper productive Coal-measures Lower barren measures and limestone
	Moscovien or Westphalian	Lower Coal-measures Millstone grit Yoredale series	Sandstones —	Limestones with Spirifer and Fusulinellas Productus limestone	Fusulina limestone Lower Coal-measures
	Dinantian or Culm	Mountain limestone and shale Calciferous sandstone of Scotland	Posidonien schists Greywackés Carboniferous limestone	Coal-measures Productus beds	Conglomerate Limestones and shales of the Appalachian
DEVONIAN (EIFELIAN)	Famenian	Pilton and Petherwyn beds —	Cypridina slates Clymenia beds	Red Sandstone —	Red Sandstone of Catskill —
	Frasnidan	Ilfracombe and Plymouth beds	Gouiatite beds	Marine limestone and marl	Chemung and Portage beds
	Givetian	—	Stringocephalus limestone	—	Hamilton beds
	Eifelian	—	Calceola beds	Lower Red Sandstone	Upper Helderberg
	Coblenzian	Lynton beds	Coblenz beds	—	Oriskany Sandstone
	Gerdinnian	—	Quartzite and schists	Absent (?)	Lower Helderberg

prepare us to find that some plants having a vast geographical range may also have endured from the period of the Upper Devonian to that of the Millstone Grit.

The strata containing this remarkable flora is often called the Erian or Ursa stage.

The Carboniferous strata of North America form a number of isolated basins, the result of folding and denudation like those of Europe (see fig. 566). In the Appalachians, the Carboniferous strata are much folded and contorted, and the coal-beds are converted into anthracite.

In the Eastern States of North America the Permian is represented by the 'Upper Barren Measures' (sub-Carboniferous of some authors). These beds conformably overlie the Carboniferous, and have so many fossils common to that great division that American geologists have refused to separate them as a distinct system.

The Permian strata of Texas consist of arenaceous and argillaceous beds, generally of a reddish colour; the formation is, according to Dr. C. A. White, about 1,000 feet in thickness, and overlies undoubted Carboniferous rocks.

In the Southern and Western States (Texas, Nebraska, &c.), a great series of beds is found containing, according to Cope, a great number of Permian Amphibians and Reptiles.

NEWER PALÆOZOIC ROCKS OF OTHER PARTS OF THE WORLD

The Devonian strata are recognised in Australia, and probably representatives of the Old Red Sandstone also exist, and these are overlaid by strata containing a true Carboniferous flora.

The Productus limestone of the Salt Range in Northern India is the formation in which the rich and interesting marine fauna of the Permian was first discovered by Waagen. The Permian marine strata here lie upon Carboniferous rocks, and are succeeded by others of Triassic age, containing a peculiarly interesting marine fauna in which *Goniatites* are mingled with several genera of *Ammonites*, some of which exhibit the peculiar Ceratite-like lobes.

In India the Permian appears to be represented not only by the strata of the Salt Range, but also by the Talchir and Damuda beds with a rich flora.

The general parallelism of the Older Palæozoic rocks in the chief districts in which they are developed, and the names given to the successive stages by European geologists, are indicated in the table on the preceding page.

For a discussion of the correlation of the Newer Palæozoic rocks of different parts of Europe, the student is referred to De Kayser and Lake's 'Comparative Geology.' The most recent views on the relations of the Newer Palæozoic rocks of North America to those of Europe will be found in the Correlation papers of the U. S. Geological Survey. 'Devonian and Carboniferous,' by H. S. Williams (Bull. 80), and 'The Texan Permian,' by C. A. White (Bull. 77). An account of the Permian marine fauna will be found in the monographs of Waagen, Karpinsky, and White.

THE OLDER PALÆOZOIC ERA

CHAPTER XXIV

THE SILURIAN SYSTEM

Classification of Silurian rocks—Characteristics of the Marine Flora and Fauna of the Silurian—Graptolites—Corals—Echinodermata—Brachiopoda—Gastropoda—Cephalopoda — Fish — British representatives—Shropshire—North Wales—Lake District—Scotland—Details of strata in the typical area—Upper Ludlow—Lower Ludlow—Aymestry Limestone—Oldest known fossil fish—Wenlock Limestone—Wenlock Shale—Woolhope Limestone—Tarannon Shales and Denbighshire Grits—Upper and Lower Llandovery rocks—May-Hill beds.

Nomenclature and classification of the Silurian strata. After William Smith had established the principle that strata may be identified by their organic remains, and had applied this important principle in his classification of the series of formations between the Mountain Limestone and the Chalk, Sedgwick and Murchison determined to investigate the formations below the Old Red Sandstone, and to group them also according to the principles of classification which had been so successfully employed in the case of the Mesozoic rocks. The former geologist chose as the scene of his researches North Wales, and the latter the Western Counties of England bordering upon Wales. When they came to compare their results, the two explorers had no difficulty in recognising the fact that the strata studied by Sedgwick were the older ones, and these it was agreed to call the Cambrian, while the newer beds investigated by Murchison were called Silurian, after the ancient British tribe (Silures) who had inhabited the district where they are best developed. As time went on, however, it soon became manifest that the Silurian system of Murchison to some extent overlapped the Cambrian of Sedgwick.

In Bohemia the whole series of the Older-Palæozoic rocks are admirably developed, and in their lower members fossils are much more abundant and better preserved than in this

country. These Bohemian strata found a very able investigator in Barrande, whose careful study of the fossils of the Older-Palæozoic era established the important conclusion that it is characterised by three very distinct faunas. The beds containing the oldest of these faunas are now universally grouped under Sedgwick's name, as the Cambrian system. The beds containing the third fauna are called Silurian; but those authors who still continue to call the beds containing the second fauna by Murchison's name speak of the beds with the third fauna as *Upper* Silurian. Other names which have been applied to this highest system of the Older Palæozoic are 'Murchisonian' by D'Orbigny, and 'Bohemian' and 'Gothlandian' by De Lapparent; but the name Silurian, which has the claim of priority, is now almost universally employed by geologists all over the world.

Following Murchison's original classification, the Silurian is regarded as consisting of three members—the Ludlow, at the top; the Wenlock, in the middle; and the Llandovery, or May-Hill Beds, at the base.

Characteristics of the Silurian Fauna and Flora.—Several very interesting algæ (seaweeds) have been recognised in the Silurian rocks, including the remarkable form known as *Pachytheca*.

Among the lowest forms of animal life present in the Silurian rocks are the Graptolites, usually referred by zoologists to the order of the Hydrozoa. The Silurian graptolites are nearly all single forms, like *Monograptus* (fig. 567), though a few double forms occur at the base of the system. Branched forms of Graptolites, so common in the Ordovician, are quite unknown in the Silurian, and the whole order of Graptolita or Rhabdophora appears to have died out shortly after the close of the Silurian.

Fig. 567.

Monograptus priodon, Gein., nat. size.
Ludlow and Wenlock Shales, and Bala group.

A second extinct order abundantly represented in the Silurian, and also referred by zoologists to the Hydrozoa, was that known as Stromatoporoidea. The Stromatoporoids had coral-like, calcareous skeletons made up of a number of concentric layers; they lived on abundantly into the Newer Palæozoic Era.

The true Corals, which are very abundant, are represented by many Tetracoralla (Rugosa), including both forms like *Omphyma* (fig. 568), which are simple, some of them being operculate like *Goniophyllum*, and compound forms like *Acervularia Stauria*, &c. With these we have many of the so-called *Tabulata*,

including such characteristic genera as *Halysites* (fig. 569) and *Favosites* (fig. 570), the systematic position of which is still regarded by naturalists as very doubtful.

Fig. 568.

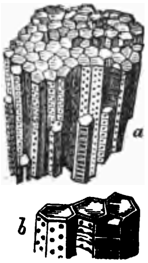
Omphyma turbinata, L. sp., ½.
(*Cyathophyllum*, Goldf.)
Wenlock Limestone, Shropshire.

Fig. 569.

Halysites catenularia, L. sp., ½.
Upper and Lower Silurian.

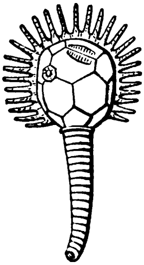
The Echinodermata of the Silurian include great numbers of Crinoids, all belonging to the Palæocrinoidea or Tesselata, in which the plates composing the calyx are fused

Fig. 570.



Favosites gothlandica, Lam. Dudley.
a. Portion of a large mass; less than the natural size.
b. Magnified portion, to show the pores and the partitions in the tubes.

Fig. 571.



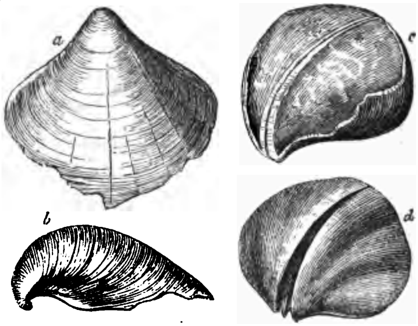
Pseudocrinites bifasciatus, Pearce, ⅔.
Wenlock Limestone, Dudley.

together. *Cyathocrinus*, *Taxocrinus*, *Crotalocrinus* are all abundant genera. The remarkable Cystoidea are represented by *Echinosphærites*, *Caryocrinus*, and *Pseudocrinites*. In

addition we have a few forms of Echini (*Bothriocidaris*, *Palæchinus*, &c.), and of Star-fish (*Protaster*, &c.).

Bryozoa are known in the Silurian, but are not abundant;

Fig. 572.

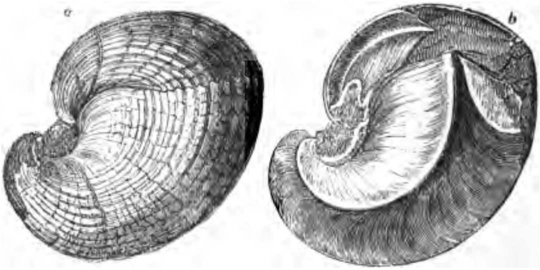


Pentamerus oblongus, Sow., nat. size. Upper and Lower Llandovery beds.

a, *b*. Views of the shell itself, from figures in Murchison's 'Sil. Syst.'
c. Cast with portion of shell remaining, and with the hollow of the central septum filled with calc spar.
d. Internal cast of a valve, the space once occupied by the septum being represented by a hollow, in which is seen a cast of the chamber within the septum.

the Brachiopoda, however, form a large and very important part of the marine fauna. Among the most characteristic genera are *Pentamerus* (figs. 572, 573), with the subgenus *Stricklandinia*

Fig. 573.

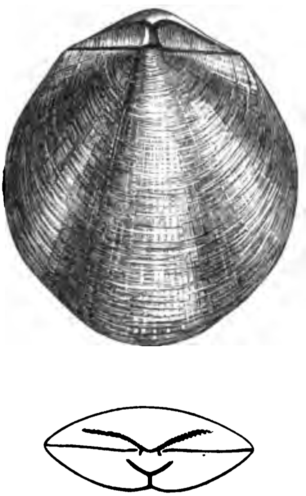


Pentamerus Knightii, Sow. ½ nat. size. Aymestry.

a. View of both valves united. *b*. Longitudinal section through both valves, showing the central plates or septa.

(figs. 574, 575). Many forms of *Orthis* (fig. 576), *Strophomena* (fig. 577), *Atrypa* (fig. 578), with *Rhynchonella* (figs. 579, 580) and *Lingula* (fig. 581), also occur.

Fig. 574.



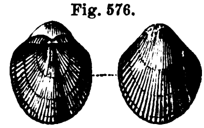
Stricklandinia (*Pentamerus*) *lens*, Sow., nat. size.

The lower figure is a transverse section, close to the hinge.

Fig. 575.

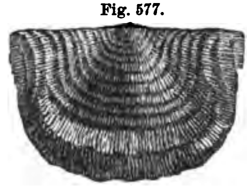
Stricklandinia (*Pentamerus*) *lirata*, Sow., ½.

Fig. 576.



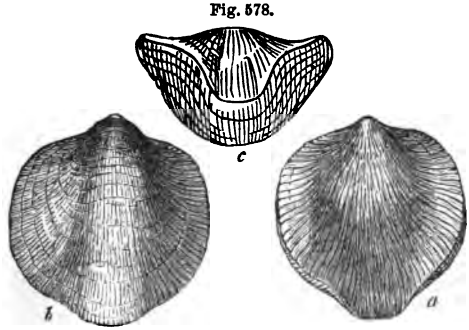
Orthis elegantula, Dalm., nat. size. Var. *orbicularis*, Sow. Upper Ludlow.

Fig. 577.



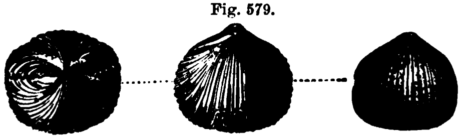
Strophomena (*Leptæna*) *depressa*, Sow., nat. size. Wenlock and Ludlow Rocks.

Fig. 578.



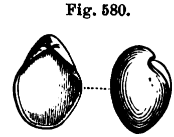
Atrypa reticulata, L., nat. size. Aymestry.
a. Upper valve. *b.* Lower valve. *c.* Anterior margin of the valves.

Fig. 579.



Rhynchonella Wilsoni, Sow., nat. size. Aymestry.

Fig. 580.



Rhynchonella navicula, Sow. nat. size. Ludlow Beds.

As compared with the Brachiopoda, the Lamellibranchiate shells are very rare in the Silurian, the most characteristic form being *Cardiola*.

Fig. 581.

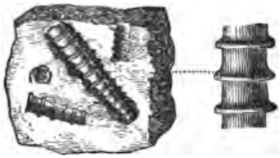
Lingula Lewisii, Sow., nat. size. Abberley Hills.

The Gastropoda are numerous and interesting, including *Turbo*, *Capulus*, and other holostomatous forms. Among the *Pteropods* we have the interesting *Tentaculites* (fig. 582).

Among the Cephalopods of the Silurian we have no representatives of Ammonoidea. *Nautilus* is present, with many forms of *Orthoceras* (fig. 583), *Lituites* (fig. 585), *Phragmoceras* (fig. 584), *Cyrtoceras*, *Gomphoceras*, *Endoceras*, &c.

The Arthropods are represented in the Silurian by many Trilobites, among which may be mentioned *Calymene* (fig. 586), *Phacops* (fig. 587), *Sphærexochus* (fig. 588), and *Homalonotus* (fig. 589).

Fig. 582.



Tentaculites annulatus, Schloth. Interior casts in sandstone. Upper Llandovery, Eastnor Park, near Malvern. Natural size and magnified.

Fig. 583.

Fragment of *Orthoceras ludense* J. Sow., ½. Leintwardine, Shropshire.

Fig. 584.

Phragmoceras ventricosum, J. Sow. (*Orthoceras ventricosum*, Stein.) Aymestry. ½ nat. size.

Fig. 585.

Lituites (Trochoceras) giganteus, J. Sow. Near Ludlow; also in the Aymestry and Wenlock Limestones. ½ nat. size.

The Eurypterida (*Pterygotus* and *Eurypterus*) are found for the first time in the Silurian.

Cirripedia are represented in the Silurian by the remarkable *Turrilepas*, Ostracoda by *Leperditia* and *Beyrichia*, and the Limulidæ make their first appearance in *Neolimulus*.

Fig. 586.

Calymene Blumenbachii, Brong., [illegible]; coiled up. Ludlow, Wenlock, and Bala Beds.

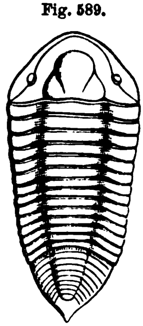
Fig. 587.

Phacops (*Asaphus*) *caudatus*, Brong., [illegible]. Wenlock and Ludlow Rocks.

Fig. 588.

Sphærexochus mirus, Beyrich, nat. size; coiled up; Wenlock Limestone, Dudley; also found in Ohio N. America.

Fig. 589.



Homalonotus delphinocephalus, Green sp., [illegible]. Wenlock Limestone, Dudley Castle.

Fig. 590.

Onchus tenuistriatus, Ag., nat. size. Bone-bed. Upper Silurian; Ludlow.

Fig. 591.

Shagreen scales of a placoid fish, *Thecodus parvidens*, Ag. Bone-bed. Upper Ludlow.

Fig. 592.

Plectrodus mirabilis, Ag., nat. size. Bone-bed. Upper Ludlow.

Fishes belonging to Selachian and to Ganoid genera are found, their remains being particularly abundant in the celebrated 'bone-bed' of Ludlow (figs. 590–592).

British Representatives of the Silurian System.—The Ludlow strata, which are 2,000 feet thick, consist of the Ledbury

Shales and Downton Sandstone or 'passage-beds' (Tilestones of Murchison), of fine-grained, yellowish sandstones which easily weather into a soft muddy state, and hard, red grits, with the Ludlow shales below. These latter sometimes contain concretionary limestones, and at Aymestry show a bed of hard crystalline argillaceous limestone in their upper portion. The Aymestry limestone is distinguished by containing numerous specimens of *Pentamerus Knightii*, Sow. (fig. 573, p. 400), with *Lingula Lewisi*, Sow. (fig. 581, p. 402), *Rhynchonella Wilsoni*, Sow. (fig. 579, p. 401), *Atrypa reticulata*, L. (fig. 578, p. 401), and many other species of Brachiopoda, with Trilobites, Corals, &c. The Ludlow shales contain Cephalopods like *Orthoceras*, *Phragmoceras*, and *Lituites*, with one species of Graptolite (*Monograptus priodon*, Gein.), while star-fish, both Asteroidea and Ophiuroidea, are by no means rare in it. In the thin 'bone-bed' near the top of the series, and also scattered through the strata, we find remains of fish and Eurypterida.

The Wenlock consists of the well-known Wenlock or Dudley limestone, with the Wenlock shale below it and the Woolhope limestone at its base. The limestones of this series are of concretionary character and crowded with exquisitely preserved fossils, among which Crinoids, Corals, Brachiopods, and Trilobites are particularly abundant. The Wenlock limestones make a well-marked escarpment above the underlying shales; the whole series having a thickness of 1,600 feet.

Between the Llandovery and Wenlock series we have the Tarannon Shales and Denbighshire Grits of North Wales, a series of beds containing a few of the fossils of the typical Wenlock and Llandovery beds with many Graptolites.

The Llandovery or May-Hill Beds consist of sandstones and shales abounding in Brachiopoda, among which *Pentamerus oblongus*, Sow. (fig. 572), *Stricklandinia lirata*, Sow. (fig. 575), *S. lens*, Sow.) (fig. 574), *Orthis calligramma*, Dalm., *O. elegantula*, Dalm. (fig. 576), *Strophomena compressa*, Dalm. (fig. 577), are particularly abundant. The beds are from 1,000 to 2,000 feet in thickness.

In the Lake district and the South of Scotland all the members of the Silurian system pass into masses of mudstone with numerous Graptolites (graptolitic facies). Numerous zones, each distinguished by special forms of Graptolites or Trilobites, have been recognised; but the exact correlation of these with the divisions in the typical Silurian area is still somewhat doubtful.

The three members of the Silurian system, as exhibited in the English districts where they are best developed, have been classified as follows:—

	Shropshire and Wales	Lake District
Ludlow or Clunian beds (including the Downtonian)	Ledbury shales, Downton sandstone } Passage beds Upper Ludlow beds (with bone-bed) Aymestry limestone	Kirkby-Moor flags
Wenlock or Salopian	Lower Ludlow beds	Bannisdale slates
	Wenlock limestone	Coniston grits
	Wenlock shale and Woolhope or Barr limestone	Coniston flags

	Shropshire and Wales	Lake District
May-Hill, Llandovery or Valentian	Tarannon shales	Browgill beds
	May-Hill sandstone (Upper Llandovery)	Stockdale shales
	Lower Llandovery	Skellgill beds

In Scotland, as in the Lake District, the conspicuous beds of limestone are wanting, and the formations are represented by thick masses of black slate, occasionally containing graptolites, which alternate with flagstones and greywackés. In the Pentland Hills, local representatives of the Ludlow and Wenlock divisions occur, while the Tarannon Shales are represented by the Gala beds, and the Llandovery (Skelgill) Shales by great masses of black shales that cover a large area in the Border Country and are known as the Birkhill Shales.

The minor subdivisions of the Silurian in the typical area (Salopian type) are described in the following pages.

1. **Ludlow Formation.**—This has been subdivided into two parts—the Upper Ludlow and the Lower Ludlow. Each of these may be distinguished near the town of Ludlow, and at other places in Shropshire and Herefordshire, by peculiar organic remains; but out of 392 species found in the Ludlow formation as a whole, not more than 5 per cent. are common to the overlying Devonian, and nearly all of those are fish and Crustacea. On the other hand, 129 of these species occur in the underlying Wenlock deposits.

a. **Upper Ludlow,** *Downton Sandstone.*—At the top of this subdivision there occur beds of fine-grained yellowish sandstone and hard reddish grits which were formerly referred by Sir R. Murchison to the Old Red Sandstone, under the name of 'Tilestones.' In mineral character this group forms a transition from the Silurian to the Old Red Sandstone; but it is now ascertained that the fossils agree in great part specifically, and in general character entirely, with those of the underlying Upper Ludlow rocks, many passing upwards. Among these are *Orthoceras bullatum,* Sow., *Platyschisma helicites,* Sow. sp., *Bellerophon trilobatus,* Sow., *Chonetes latus,* Sow., &c. Crustacea of the genera *Pterygotus, Eurypterus,* and *Stylonurus* are met with, and Fish—*Cephalaspis, Pteraspis, Scaphaspis, Auchenaspis,* and *Eukeraspis.*

Bone-bed of the Upper Ludlow.—At the base of the Downton sandstones there occurs a bone-bed which deserves especial notice as affording the most ancient example of fossil fish occurring in any considerable quantity. It usually consists of one or two thin layers of brown bony fragments near the junction of the Old Red Sandstone and the Ludlow rocks. It is seen near the town of Ludlow, where it is three or four inches thick, and has been traced to a distance of 45 miles from that point into Gloucestershire and other counties, being commonly not more than an inch thick, but varying to nearly a foot. Near Ludlow two bone-beds are observable, with 14 feet of intervening strata full of Upper Ludlow fossils. Immediately above the upper fish-bed, numerous small globular bodies have been found, which were once considered to be the sporangia of a lycopodiaceous land-plant, but have now been shown to be the remains of a seaweed; it is called *Pachytheca sphærica,* J. Hook.

Some of the fish remains are of the placoid order, and may be referred to the genus *Onchus,* to which the spine (fig. 590) belongs. The minute scales (fig. 591) may also belong to a placoid fish. The jaw and teeth of another predaceous genus, *Plectrodus mirabilis,* Ag. (fig. 592), have also been detected, together with some specimens of *Pteraspis ludensis,* Salt. As is

usual in bone-beds, the teeth and bones are, for the most part, fragmentary and rolled. Associated with these fish defences or Ichthyodorulites, and closely resembling them, are numerous prongs or tail spines of large phyllopod crustaceans which have been, and still are frequently, mistaken for the dorsal spines of fish.

Grey Sandstone and Mudstone, &c.—The next subdivision of the Upper Ludlow consists of grey, calcareous sandstone, or very commonly a micaceous rock, decomposing into soft mud, and contains, besides the shells mentioned at p. 404, *Lingula cornea*, Sow., *Orthis orbicularis*, Sow., a round variety of *O. elegantula*, Dalm. (fig. 576), *Modiolopsis platyphylla*, Salt., *Grammysia cingulata*, His. sp., all characteristic of the Upper Ludlow. The lowest or mudstone beds contain *Rhynchonella navicula*, Sow. (fig. 580), which is common to this bed and the Lower Ludlow. Usually, in Palæozoic strata older than the Coal, the Brachiopoda greatly outnumber the Lamellibranchiata. But it is remarkable that in these Upper Ludlow rocks the Lamellibranchiata outnumber the Brachiopoda, there being 56 species of the first and only 27 of the last group. Amongst the genera represented are *Avicula* and *Pterinea*, *Cardiola*, *Ctenodonta* (subgenus of *Nucula*), *Orthonota*, *Modiolopsis*, and *Palæarca*.

Some of the Upper Ludlow sandstones are ripple-marked, thus affording evidence of gradual deposition; and the same may be said of the accompanying fine argillaceous shales, which are of great thickness, and have been provincially named 'mudstones.' In some of these shales, stems of Crinoidea are found in an erect position, having evidently become fossil on the spots where they grew at the bottom of the sea. The facility with which these rocks weather into mud, proves that, notwithstanding their antiquity, they have not been subjected to any great chemical changes, but are nearly in the state in which they were originally deposited.

b. **Lower Ludlow beds.**—The chief mass of this formation consists of a dark grey argillaceous shale with calcareous concretions, having a maximum thickness of 1,000 feet. In some places, and especially at Aymestry in Herefordshire, a subcrystalline and argillaceous limestone, sometimes 50 feet thick, overlies the shale, and appears rising above the denuded Lower Ludlow shales. It is not very continuous, so that the shales of the Lower and the strata of the Upper Ludlow come together around it. Sir R. Murchison classed this Aymestry limestone as holding an intermediate position between the Upper and Lower Ludlow. It is distinguished by the abundance of *Pentamerus Knightii*, Sow. (fig. 578), also found in the Wenlock limestone and shale. This genus of Brachiopoda is exclusively Palæozoic. The name was derived from *πέντε*, *pente*, five, and *μέρος*, *meros*, a part, because both valves are divided by a central septum, making four chambers, and in one valve the septum itself contains a small chamber, making five. The size of these septa is enormous compared with those of any other Brachiopod shell; and they must nearly have divided the animal into two equal halves; but they are, nevertheless, of the same nature as the septa or plates which are found in the interior of *Spirifera*, *Uncites*, and many other shells of this order. Murchison and De Verneuil discovered this species dispersed in myriads through a white limestone of Silurian age on the banks of the Is, on the eastern flank of the Urals in Russia, and a similar species is frequent in Sweden.

Three common shells in the Aymestry limestone are—*Lingula Lewisii*, Sow. (fig. 581); *Rhynchonella Wilsoni*, Sow. (fig. 579), which is also common to the Lower Ludlow and Wenlock limestones; *Atrypa reticulata*, L. (fig. 578), which has a very wide range, being found in every part of the Silurian system, and even passes up into the Middle Devonian series.

The Aymestry Limestone contains many shells, especially bra-

chiopoda, corals, trilobites, and other fossils, amounting in the whole to 84 species, all except three or four being common to the beds either above or below.

The Lower Ludlow Shale contains many large Cephalopoda not known in newer rocks, such as *Phragmoceras* and *Lituites*. (See figs. 584, 585.) The latter is partly straight and partly convoluted in a very flat spire. *Orthoceras ludense*, J. Sow. (fig. 583) also occurs.

A species of Graptolite, *Monograptus priodon*, Gein. (fig. 567, p. 398), occurs plentifully in the Lower Ludlow. The Graptolites will be noticed further on, but they became extinct during the Ludlow age.

Star-fish, as Sir R. Murchison pointed out, are by no means rare in the Lower Ludlow rock. These fossils, of which 6 extinct genera are now known in the Ludlow series, represented by 18 species, remind us of various living forms of the orders *Asteroidea* and *Ophiuroidea* now found in our British seas, but their anatomical details differ greatly.

The two great orders of the class Crustacea in the Ludlow rocks are the Merostomata and the Phyllopoda, and they predominate over the Trilobita, which were waning as a great group, and were destined to become gradually extinct during the Devonian, Carboniferous, and Permian periods.

Of all the genera of Trilobita so common in the Silurian and Cambrian formations, only two, *Homalonotus* and *Phacops*, survived the changes which introduced the Devonian formation. Six of the species of Merostomata pass up into the Old Red Sandstone.

Oldest known fossil fish. Until 1859 there was no fossil fish known older than the bone-bed of the Upper Ludlow; but *Scaphaspis* (*Pteraspis*) *ludensis*, Salt., has been found in Lower Ludlow shale at Church Hill, near Leintwardine, in Shropshire, by the late J. E. Lee, of Caerleon.

These fish were long regarded as the oldest representatives of the vertebrate series, but Dr. Lindström has recently found *Cyathaspis* in the Gothland Limestone of Sweden, which is of Wenlock age, while, in America, Walcott has described fish-remains as occurring in strata that are believed by him to be of Ordovician age.

2. **Wenlock Formation.**—We next come to the Wenlock formation, which has been divided into *a*, Wenlock limestone and Wenlock shale; and *b*, Woolhope limestone, Tarannon shale, and Denbighshire grits.

a. Wenlock Limestone.—This limestone, otherwise well known to collectors by the name of the Dudley Limestone, forms a continuous ridge in Shropshire, ranging for about 20 miles from S.W. to N.E., about a mile distant from the nearly parallel escarpment of the Aymestry limestone. This ridgy prominence is due to the solidity of the rock, and to the softness of the shales above and below it. Near Wenlock it consists of thick masses of grey subcrystalline limestone, replete with corals, Encrinites, and Trilobites. It is essentially of a concretionary nature; and the concretions, termed 'ball-stones' in Shropshire, are often very large, even 80 feet in diameter. They are composed chiefly of carbonate of lime, the surrounding rock being more or less argillaceous. Sometimes this limestone is oolitic. All the limestones of the Upper Silurian form great lenticular masses, and thin out so as to have their space occupied by the shaly strata of the lower and upper divisions of the same great age.

Among the corals in which this formation is so rich, 76 species being known, the 'Chain-coral,' *Halysites catenulatus*, L. sp. (fig. 569), may be pointed out as one very easily recognised, and widely spread in Europe, ranging through all parts of the Silurian and Ordovician, from the Ludlow to near the bottom of the Llandeilo rocks. Another coral, the *Favosites gothlandica*, Lam. (fig. 570), is met with in profusion, in large hemispherical masses, which break up into columnar and prismatic fragments. Another common form in

the Wenlock limestone is the *Omphyma turbinata*, L. sp. (fig. 568), which, like many of its modern companions, reminds us of some cup-corals; but all the Silurian genera belong to the Palæozoic type before mentioned (p. 351).

Among the numerous Crinoidea, several peculiar species of *Cyathocrinus*, *Crotalocrinus*, &c., contributed their dismembered calcareous stems, arms, and cups towards the composition of the Wenlock limestone. Of Cystoidea there are a very few remarkable forms, most of them peculiar to the Silurian system; as, for example, the *Pseudocrinites*, which was furnished with pinnated fixed arms, as represented in the figure (fig. 571, p. 399).

The Brachiopoda preponderated over most of the other groups, no less than 22 genera and 101 species being found. *Atrypa Barrandei*, David., *Orthis æquivalvis*, David., *Siphonotreta anglica*, Mor., are special forms; about 11 species pass up into the Aymestry limestone. Examples are *Atrypa reticulata*, L. sp., and *Orthis elegantula*, Dalm.

The Crustacea are represented by Eurypterida, which appear for the first time, including the genera *Pterygotus* and *Eurypterus*, and by Ostracoda and Trilobites. The Trilobite *Calymene Blumenbachii*, Brong. (fig. 586), is common, and it ranges from the Llandeilo group to near the top of the Silurian. It is often found coiled up like the common wood-louse, and this is so usual a circumstance among certain genera of Trilobites as to lead us to conclude that they must have habitually resorted to this mode of protecting themselves when alarmed. *Sphærexochus mirus*, Beyr. (fig. 588), is almost globular when rolled up, the forehead or glabella of this species being extremely inflated. The other common species are *Encrinurus punctatus*, Emmr. sp., and *Phacops caudatus*, Brong. (fig. 587), which is conspicuous for its large size and flattened form. In the genus *Homalonotus* the tripartite division of the dorsal crust is almost lost (see fig. 589); it is characteristic of this division of the Silurian series.

Wenlock shale.—Fine grey and black shales, with most of the fossils common to the overlying limestone. In the Malvern district it is a mass of finely levigated argillaceous matter, attaining, according to Professor Phillips, a thickness of 640 feet; but it is sometimes more than 1,000 feet thick in Wales, and is worked for flagstones and slates. The prevailing fossils, besides corals and Trilobites, and some Crinoidea, are several small species of *Orthis*, *Atrypa*, and *Rhynchonella*, and numerous thin-shelled species of *Orthoceras*.

About six species of Graptolites occur in this shale, *Graptolithus Flemingii*, Salt., being peculiar, whilst *Monograptus priodon*, Gein. (fig. 567), ranges through into the Ludlow group.

b. Woolhope limestone underlies the Wenlock shale, and consists of grey shales, with nodular limestone. It is well seen in the valley of Woolhope, and at Malvern there is much shale beneath. The fossils of the Woolhope limestone are principally Crustacea, all of the Trilobite group, and Brachiopoda. Examples of the fossils are *Phacops caudatus*, Brong. (fig. 587), *Homalonotus delphinocephalus*, Green sp. (fig. 589), *Strophomena imbrex*, Pand., *Rhynchonella Wilsoni*, Sow. (fig. 579), and *Eucalyptocrinus polydactylus*, M'Coy. This limestone is in large lenticular masses, and is overlapped at its edges by the underlying shales which then join continuously with the Wenlocks above.

There is a very persistent set of beds of fine light grey or blue shales, (termed 'paste-rock'), which lie on the Upper Llandovery strata over a considerable tract of country from the Conway into Caermarthenshire, just as the Woolhope limestone covers these last-mentioned strata in Shropshire and Herefordshire. These Tarannon shales are 1,000 to 1,500 feet thick in places, and contain numerous species of *Graptolites*, corals of the genera *Favosites* and *Cyathophyllum*: one of the Crinoidea, *Actinocrinus pulcher*,

Salt., which passes up into the Lower Ludlow, and the Brachiopod *Lingula Symondsii*, Salt. The Tarannon shales are covered, in Denbighshire, by grits and sandstones at least 3,000 feet thick, which pass into hard shales of probably Wenlock age. These Denbighshire grits form mountain ranges in North and South Wales, and produce a very sterile soil. They were formed probably during the time of the accumulation of the Wenlock deposits. It is interesting to note that these grits do not pass up into the base of the Old Red Sandstone, but lie unconformably below it, indicating great terrestrial movements before its deposition. This is very different from the state of things sixty miles off, where the Old Red rests conformably on the underlying Silurian.

Dr. Hicks found vegetable remains in the Denbighshire grits, such as the *Pachytheca* already noticed (p. 405), and a remarkable marine Alga *Nematophycus*, which probably resembled the great branching *Lessonia* of the present day in its habit. Many of these great marine Algæ of the existing ocean measure 80 feet in length and a foot in diameter.

The marine fossils include sponges (*Cliona prisca*, M'Coy); corals (*Favosites aspera*, D'Orb., *Syringopora serpens*, L. sp.); there are 19 species of Brachiopoda, all common to the Wenlock limestone; and Cephalopoda, of the genera *Orthoceras*, *Phragmoceras*, and *Cyrtoceras*.

3. **Llandovery group — Upper Llandovery rocks.**—The succession of these strata has been noticed, and it must be remembered that the Wenlock group rests conformably on the Upper Llandovery beds, which in their turn cover the worn and denuded surfaces of the disturbed, curved, and faulted underlying rocks to which they are unconformable. Upper Llandovery rocks, named May-Hill Sandstones by Sedgwick after the locality in Gloucestershire, where they are so well displayed, appear on the coast of Pembroke at Marloes Bay. They range across South Wales until they are overlapped by the Old Red Sandstone and emerge again in Caermarthenshire, and can be traced north-eastwards as a narrow strip at the base of the Silurian series, from a few feet to 1,000 feet or more in thickness, as far as the Longmynd, where, as a conglomerate, they wrap round that ancient pre-Cambrian ridge and disappear. In the course of this long tract they pass successively and unconformably over Lower Llandovery, Caradoc, Llandeilo, and pre-Cambrian rocks. They consist of brownish and yellowish sandstones with calcareous nodules, having sometimes a conglomerate at the base derived from the waste of older rocks.

The fauna of the Upper Llandovery rocks consists of 240 species, and there are only 91 of these which do not pass up into the Wenlock group, so that the physical unconformity of the two groups is accompanied by no palæontological break of importance. The Lamellibranchiata become of importance in this fauna, as do the Gastropoda of the genera *Holopella*, *Acroculia*, *Rhaphistoma*, and *Turbo*. The Brachiopoda number in species more than double those of any other class, there being 65 species, including *Pentamerus oblongus*, Sow. (fig. 574), *Stricklandinia lirata*, Sow. sp. (fig. 575), *S. lens*, Sow. sp. (fig. 574), *Orthis calligramma*, Dalm., *O. elegantula*, Dalm., *Strophomena compressa*, Sow. Among the corals *Favosites* and *Heliolites* are found. The first Echinoid occurs, *Palæchinus Phillipsiæ*, Forbes, and its plates abut one against the other and do not overlap. *Tentaculites* is found (fig. 582), and also *Cornulites*.

Pentamerus oblongus, Sow., accompanied by *Stricklandinia lirata*, Sow. sp., have a wide geographical range, being also met with in the same part of the Silurian series in Russia and the United States. The Trilobites are of the genera *Illænus*, *Calymene*, *Encrinurus* and *Phacops*.

Lower Llandovery rocks. The Upper Llandovery strata rest unconformably on the Lower, and

there is a clear physical break; but the palæontological break is not of corresponding importance to it. The hard slaty rocks and conglomerates, from 600 to 1,000 feet in thickness, of the Lower Llandovery group contain a fauna of 68 genera and 204 species. More than one-half (104) of the species pass up into the Upper Llandovery strata. Etheridge explains that the lapse of time which occurred between the disturbance of the Lower Llandovery rocks and the deposition of the Upper, was not of sufficient duration to cause the extinction or migration of the older fauna or the introduction of a perfectly new one. The physical change in all probability was not very widely felt.

The Brachiopoda are numerous in the Lower Llandovery rocks, and the genera *Pentamerus* and *Stricklandinia* appear for the first time; the species with the most numerous individuals being *Stricklandinia lens*, Sow. sp., *S. lirata*, Sow. sp., and *Pentamerus oblongus*, Sow. sp., *P. undatus*, Sow. sp., especially the first named. The genus *Murchisonia* occurs among the Gastropoda, and *Bellerophon* with *Conularia* (a Pteropod) is also represented. The Trilobites are remarkable, because no less than 18 species pass into this group of strata from lower rocks, and 10 pass upwards into the Upper Llandovery group; and this passage of forms is noticed also in the Actinozoa, but in a greater degree. The Graptolites are very rare in the English Lower Llandovery strata.

It appears that the Lower Llandovery strata, having a fauna, the half of which lived on, in the Upper Llandovery rocks, and 105 species of which are also found fossil in the underlying Caradoc or Bala strata, are occasionally unconformable to these last. The importance of this palæontological continuity, associated with unconformity, may be estimated by the fact that the underlying Caradoc formation contains 614 species, and thus one-sixth of that fauna passes upwards into the Silurian.

Sir Roderick Murchison's 'Siluria' may still be referred to by students as containing the fullest account of the strata of this age in the typical area; see also 'The Geology of South Shropshire,' by Prof. Lapworth and Mr. W. W. Watts, Proc. Geol. Ass. 1894. The works of M. Barrande contain descriptions of the numerous and well-preserved fossils of the period which are found in Bohemia. Lindström and other authors have described the Scandinavian strata and fossils, while a good summary of our knowledge of the Silurian fossils of North America will be found in Dana's 'Manual of Geology,' and in the Correlation papers of the U.S. Geological Survey.

CHAPTER XXV

THE ORDOVICIAN SYSTEM

Classification of Ordovician strata—Characteristics of the marine Fauna—Foraminifera—Graptolites—Echinodermata—Brachiopoda—Gastropoda—Cephalopoda—Worms—Trilobita and their organisation—Bala or Caradoc strata—Llandeilo beds—Arenig beds or Stiper-stones—Ordovician strata of the Lake District—Ordovician strata of Scotland.

Nomenclature and Classification of the Ordovician strata.—Much confusion in nomenclature with respect to the system of strata containing Barrande's second fauna has arisen from the unfortunate misunderstanding between Sedgwick and

Murchison. The followers of Murchison, with the powerful support of the Geological Survey, have insisted on calling the system 'the Lower Silurian,' while the supporters of Sedgwick, comprising many of his pupils at Cambridge, have named it 'Upper Cambrian.' Attempts at a compromise, like the proposal to call the period Cambro-Silurian or Siluro-Cambrian, have not met with much success; and hence those geologists who think that general convenience should be the main consideration in framing a classification and nomenclature, have gladly welcomed the suggestion of Professor Lapworth to call the disputed strata 'Ordovician.' This name is derived from the ancient British tribe (Ordovices) which inhabited the district where the strata are best developed; and hence the term may be regarded as strictly parallel in its derivation with the names Cambrian and Silurian.

D'Orbigny called this system of strata Silurian, distinguishing the true Silurian as Murchisonian, while de Lapparent applied to it the name of Armorican, subsequently withdrawing the name in favour of Lapworth's suggestion.

The dispute concerning names between Sedgwick and Murchison was not confined to the three great systems themselves, but extended to the nomenclature of the smaller divisions of the strata containing the second fauna. Most geologists now recognise a threefold division of the Ordovician, and the names applied to them by Sedgwick and Murchison respectively were as follows:—

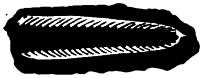
Sedgwick.	Murchison.
Bala.	Caradoc.
Llandeilo.	Upper Llandeilo.
Arenig.	Lower Llandeilo.

Characteristics of the Ordovician Fauna and Flora.—Although many of the forms regarded as seaweeds in the Ordovician and underlying Cambrian are now recognised as being the trails and markings of animals, there are some examples of true algæ. Among these must probably be classed the curious Calcareous algæ (*Girvanella*, &c.) which sometimes make up a great portion of the limestone beds, and the other obscure organisms concerned in producing rocks of oolitic and pisolitic structure.

Among the Protozoa, we have many Foraminifera, like those which have been instrumental in the formation of the Glauconite sand and Glauconite limestone of Russia. In recent years thick and important siliceous deposits, made up of Radiolarians, have been found in Scotland and other countries. As a rule, however,

neither the Foraminifera nor the Radiolaria are so well preserved as to enable us to make accurate comparisons between the early forms of these lowly organisms and their descendants of later periods. Siliceous sponges, like *Astylospongia* and

Fig. 593.

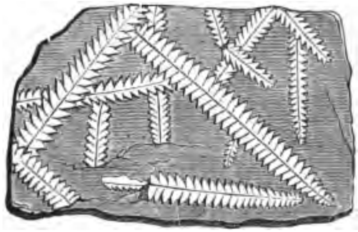


Didymograptus Murchisonii, Beck, ½.
Llandeilo flags, Wales.

Fig. 594.

Didymograptus geminus, Hisinger, sp. Sweden.

Fig. 595.

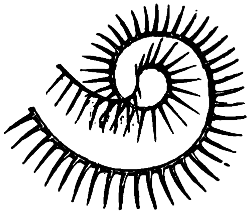


Diplograptus pristis, His., nat. size.
Llandeilo beds, Waterford.

Fig. 596.

Diplograptus folium, His.
(*Phyllograptus*.)
Dumfriesshire; Sweden.
Llandeilo flags.

Fig. 597.



Rastrites peregrinus, Barrande, nat. size.

Scotland; Bohemia; Saxony; Llandeilo flags.

Fig. 598.

a

b

Echinosphærites balticus, Eich., nat. size. (Of the family *Cystoidea*.)

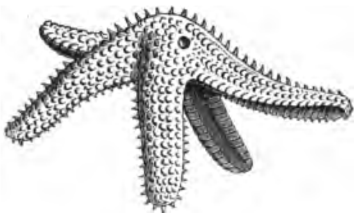
a. Mouth.
b. Point of attachment of stem.
Lower Silurian, S. and N. Wales.

Aulocopium, are not rare, and perhaps belong to synthetic forms combining characters which in later times distinguished Hexactinellid and Lithistid forms.

The Graptolites of the Ordovician are very numerous and interesting, and include great numbers of branched and double forms like *Didymograptus* (figs. 593, 594), *Diplograptus* (fig.

595), *Phyllograptus* (fig. 596), *Tetragraptus*, *Dichograptus*, &c.; with a few peculiar simple forms like *Rastrites* (fig. 597), and the complex, netlike genus *Retiolites*.

Fig. 599.

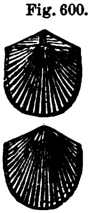


Palæaster asperrimus, Salt. Caradoc. Welshpool.

Stromatoporoidea make their appearance in the Ordovician, though they attain their maximum development in the Silurian and Devonian.

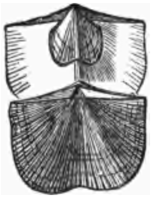
True Corals are abundant in some of the limestone beds, but do not occur in the same profusion as in the Silurian. The coral-like structures are Tetracoralla (Rugosa), Tabulate forms (Monticuliporidæ), and Hydrocorallinæ.

Fig. 600.



Orthis tricenaria, Conrad. New York; Canada. $\frac{1}{2}$ nat. size.

Fig. 601.

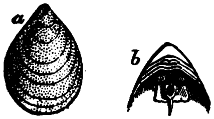


Orthis vespertilio, Sow. Shropshire; N. and S. Wales. $\frac{1}{2}$ nat. size.

Fig. 602.

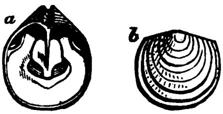
Strophomena grandis. Sow., $\frac{2}{3}$ nat. size. Caradoc Beds, Horderley, Shropshire; and Coniston, Lancashire.

Fig. 603.



Siphonotreta unguiculata, Eichwald, nat. size.
From the lowest Silurian Sandstone, 'Obolus grits,' of Petersburg.
a. Outside of perforated valve.
b. Interior of same, showing the termination of the foramen within. (Davidson.)

Fig. 604.



Obolus Apollinis, Eichwald, nat. size.
From the same locality.
a. Interior of the large or ventral valve.
b. Exterior of the upper (dorsal) valve. (Davidson, 'Palæontograph. Monog.')

Echinoderms are principally represented by *Cystoidea*, like *Echinosphærites* (fig. 598), a group which attained its maximum development at this period. The Crinoids, however, are rare in the Ordovician, while some starfish, like *Palæaster*, are found.

It is by the abundance and variety of its Brachiopod fauna that the Ordovician system is especially distinguished. Many species of *Orthis* (figs. 600, 601), *Leptæna*, and *Strophomena* (fig. 602), occur in it, with certain genera not found in any other system, like *Porambonites*, *Orthisina*, and *Platystrophia*; and others found only in the Ordovician of Russia and North America, like *Obolus* (fig. 604), *Siphonotreta* (fig. 603), *Trimerella*, &c.

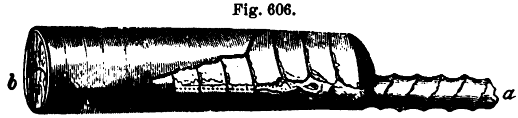
Fig. 605.

Murchisonia gracilis, Hall. Nat. size.
A fossil characteristic of the Trenton Limestone.

In striking contrast with this abundant and remarkable Brachiopod fauna, the Lamellibranchiata of the Ordovician are rare and comparatively unimportant, and no sinupalliate forms are found in it.

The Gastropoda include *Murchisonia* (fig. 605), and the remarkable form *Maclurea*. Pteropods like *Theca*, *Tentaculites*, and *Conularia* are abundant.

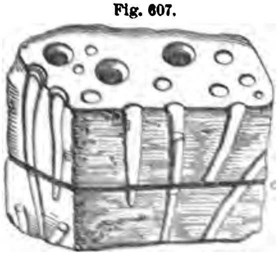
Fig. 606.



Orthoceras duplex, Wahlenb. Russia and Sweden.
(From Murchison's 'Siluria.')
a. Lateral siphuncle laid bare by the removal of a portion of the chambered shell.
b. Continuation of the same seen in a transverse section of the shell.

The Cephalopods include many forms of *Nautilus*, *Orthoceras*, and other genera of the Nautiloidea like those of the Silurian.

Fig. 607.



Arenicolites linearis, Hall.
Arenig beds, Stiper-stones.
a. Parting between the beds, or planes of bedding.

The abundance and variety of the Vermes of this period are testified to by the numerous tracks and burrows formed by these organisms (see fig. 607).

The Trilobita of the Ordovician are only inferior in numbers and variety to the Brachiopoda; among the most abundant genera are *Asaphus* (fig. 608), *Ogygia* (fig. 609), *Trinucleus* (figs. 610, 611), *Lichas*, *Acidaspis*, &c.

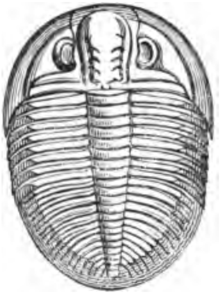
Ostracods and Phyllopods are the only Arthropods besides the Trilobites which are present in any abundance in the Ordovician.

Traces of Ganoid fish are said to have been found in the Ordovician of Colorado, but it is doubtful if the beds have really the age which has been assigned to them.

Fig. 608.

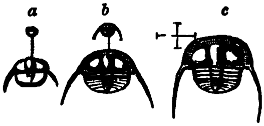
Asaphus tyrannus, Murch., ⅓.
Llandeilo ; Bishop's Castle, &c.

Fig. 609.



Ogygia Buchii, Burm., ⅓.
Syn. *Asaphus Buchii*, Brong.
Builth, Radnorshire ; Llandeilo, Caermarthenshire.

Fig. 610.



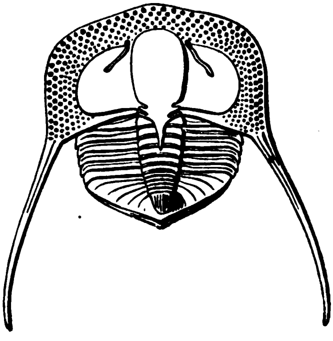
Young individuals of *Trinucleus concentricus*, Eaton.

a. Youngest state. Natural size and magnified ; the body rings not at all developed.

b. A little older. One thorax joint.

c. Still more advanced. Three thorax joints. The fourth, fifth, and sixth segments are successively produced, probably each time the animal moulted its crust.

Fig. 611.



Trinucleus concentricus, Eaton, nat. size.
Syn. *T. Caractaci*, Murch.
Ireland ; Wales ; Shropshire ; N. America ; Bohemia.

British representatives of the Ordovician System.—The Ordovician consists of three members which following the nomenclature of Sedgwick are called Bala, Llandeilo, and Arenig ; while the names adopted by Murchison and the Geological Survey for the same divisions were Caradoc, Upper Llandeilo flags, and Lower Llandeilo flags.

1. **The Bala and Caradoc group.**—The Caradoc Sandstone was so named by Murchison, from Caer Caradoc in Shropshire. It consists of shelly sandstones of great thickness, sometimes contain-

ing much calcareous matter. In the Bala district there is an upper and a lower limestone, with an intermediate series of sandy and slaty strata; the lower limestone has a great extension in North Wales.

These very fossiliferous strata contain a large number of Brachiopoda, *Strophomena grandis*, Sow. sp. (fig. 602), *S. deltoidea*, Cour. sp., *Chonetes plicata*, Sow. sp., and *Rhynchonella nasuta*, M'Coy, being amongst the characteristic species, whilst *Orthis vespertilio*, Salt. (fig. 601), and *Orthis tricenaria*, Conrad (fig. 600), are common to this group and the Llandovery. There are no less than 109 species of Brachiopoda in the group, and they outnumber the Lamellibranchiata with 76 species, as is almost always the case in the Ordovician rocks of every country. Their proportional numbers can by no means be explained by supposing them to have inhabited seas of great depth, for the contrast between the Palæozoic and the present state of things has not been essentially altered by the late discoveries made in our deep-sea dredgings. We find the living Brachiopoda so rare as to form a very small fraction of the whole bivalve fauna; whereas, in the Ordovician rocks, where the Brachiopoda reach their maximum, they are greatly in excess of the Lamellibranchiata.

There may, indeed, be said to be a continued decrease of the proportional number of Brachiopoda, as compared with that of the Lamellibranchiata, in proceeding from older to newer rocks.

The Gastropoda are very numerous, and amongst the 53 species only two are known in lower rocks, and 10 pass upwards, so that a characteristic series of 41 species exists. They indicate, as do the Lamellibranchiata, shallow-water conditions, some of the genera being *Murchisonia*, *Holopella*, *Rhaphistoma*, and *Turbo*. Pteropoda and Heteropoda are found, and there are 47 species of Cephalopoda, of which 39 are peculiar to the groups of strata. *Lituites*, *Orthoceras*, and *Cyrtoceras* are common genera.

The Crustacea are the most conspicuous fossils in this group of strata, and no less than 123 species of Trilobita have been discovered. Only 15 pass upwards, and amongst them are—*Calymene Blumenbachii*, Brong., *Encrinurus punctatus*, Emmr. sp., *Lichas laxatus*, M'Coy, and *Phacops caudatus*, Brünn. Some of the most characteristic genera are *Harpes*, *Salteria*, and *Cyclopyge*. Certain of the Trilobita found in the Caradoc group lived on into the Silurian, and *Trinucleus concentricus*, Eaton (fig. 611), *Calymene Blumenbachii*, Brong., and *Ampyx rostratus*, Sars., are examples of this.

The Trilobite order of Crustacea has a great number of genera which are found in the Palæozoic rocks, from the Permian downwards. It was at its maximum of numbers in the Caradoc age, and diminished rapidly in the Devonian, becoming rare and extinct in the Carboniferous and Permian formations. The trilobed body, with a cephalic or head-shield bearing a pair of eyes, with body rings and a hinder shield or pygidium, are well seen in most of the order. Some have the angles of the cephalic shield prolonged into long spines, like *Trinucleus* (fig. 611). Burmeister was of opinion that the Trilobita underwent a series of transformations analogous to those of living Crustaceans. Barrande has obtained complete proofs of these metamorphoses, and he has been able in more than twenty species to trace the different stages of growth from the young state, just after its escape from the egg, to the adult form. He has followed some of them from a point in which they show no eyes, no joints, or body rings, and no distinct tail, up to the complete form with the full number of segments. This change is brought about before the animal has attained a tenth part of its full dimensions, and hence such minute and delicate specimens are rarely met with. Some of his figures of the metamorphoses of the common *Trinucleus* are copied (figs. 610, 611, *a–c*, p. 415), and of *Sao* (fig. 616, p. 423).

Until recent years it was only

the upper surface of the Trilobites that was known to naturalists. But the studies of Walcott and Becher have shown that the Trilobita were furnished with numerous delicate, jointed, swimming-appendages on their under side, with antennæ attached to their head-shields.

The Rugose Corals, the Alcyonaria and Hydrocorallina, were well represented in the Bala beds by *Cyathophyllum*, *Heliolites*, and *Halysites*. The Echinodermata were represented by the Cystoidea (fig. 598), and 23 species are characteristic; one also (*Echinosphærites arachnoidea*, Forbes) passes up into the Llandovery group. The Cystoidea were stalked as a rule, and became extinct during the Devonian age. It is interesting to note that the Blastoidea, of which *Pentremites* is a well-known Carboniferous genus, began to flourish when the Cystoidea began to seriously diminish in numbers, and gained their maximum development during the Carboniferous age. All were Palæozoic. Crinoidea existed in the Caradoc age, and also Asteroidea of the genera *Palæaster* (fig. 599) and *Stenaster*.

Graptolites occur in considerable abundance, but they are chiefly found in peculiar localities where black mud abounded. The formation, when traced into South Wales and Ireland, assumes a greatly altered mineral aspect, but still retains its characteristic fossils. It is worthy of remark that when these strata occur under the form of 'trappean tuff' (volcanic ashes of De la Beche), as in the crest of Snowdon, the peculiar species which distinguish it from the Llandeilo beds are still observable. The formation generally appears to be of shallow-water origin, and in that respect is contrasted with the group next to be described. Sir A. Ramsay estimates the thickness of the Bala beds in North Wales, including the contemporaneous volcanic rocks, stratified and unstratified, as being from 10,000 to 12,000 feet.

2. **Llandeilo group.**—These strata at Llandeilo, a town in Caermarthenshire, consist of dark-coloured argillaceous and micaceous flags, frequently calcareous, with a great thickness of shales below them, generallyof a black colour. They are also seen at Abereiddy Bay in Pembrokeshire, and at Builth in Radnorshire, where they are interstratified with volcanic matter. They are conformable with the overlying Caradoc group.

A still lower part of the Llandeilo rocks consists of a black carbonaceous slate of great thickness, frequently containing sulphide of iron, and sometimes, as in Dumfriesshire, beds of anthracite are present. It has been conjectured that this carbonaceous matter may be due in great measure to large quantities of embedded animal matter, for the number of graptolites included in these slates is certainly very great. In North and South Wales 25 species of Graptolites occur in the Llandeilo flags. The double Graptolites, or those with two rows of cells, such as *Diplograptus* (fig. 595), *Climacograptus*, and *Dicranograptus*, are conspicuous. *Didymograptus* (figs. 593, 594) is a branching form with one series of cells.

The leaflike Phyllograpti (fig. 596) and the remarkable curved form Rastrites (fig. 597) are also found in the Ordovician.

The Brachiopoda number 34 species, 23 of which pass up into the Caradoc Sandstone, while five genera—*Acrotreta*, *Crania*, *Rhynchonella*, *Strophomena*, and *Leptæna*—appear for the first time.

The Lamellibranchiata are *Cardiola interrupta*, Brod., *Modiolopsis expansa*, Portl., *Ctenodonta varicosa*, Salt., and *Palæarca amygdalus*, Salt. Some pass to the Caradoc, and the genus *Cardiola* appears for the first time. *Murchisonia* and *Ophileta* are common Gastropoda, and the Pteropods belong to the genus *Theca*. Cephalopoda are not abundant in the British Llandeilo formation; but *Orthoceras*, *Endoceras*, and *Piloceras* are common genera. On the Continent of Europe the Orthoceratidæ are very common (fig. 606).

The genera *Asaphus* (fig. 608),

Ogygia (fig. 609), and *Trinucleus* (fig. 611) form a marked feature of the Trilobite fauna of this age, which comprehends 18 genera and 45 species.

3. **Arenig or Stiper-stones group.**—Next in descending order, and forming the base of the Lower Silurian, are the shales and sandstones in which the quartzose rocks called Stiper-stones in Shropshire occur. For a long time the only organic remains in these Stiper-stones were the tubular burrows of Annelids (see fig. 607, *Arenicolites linearis*, Hall), which are remarkably common in the Lowest Silurian in Shropshire, the North-west Highlands of Scotland, and in the State of New York in America. Similar burrows are now made, on the retiring of the tides, in the sands by lobworms, which are dug out by fishermen and used as bait.

Sedgwick recognised this group, which he called the Arenig or Skiddaw, and separated it from the overlying and conformable Llandeilo. Salter, however, distinguished the break between the Arenig and the underlying Tremadoc group, and Dr. Hicks has defined the succession in South Wales, and described a great fauna in the Arenigs of the St. David's district. It must be remembered that there is no stratigraphical unconformity between the Arenig and the groups above and below it; though the palæontological break is considerable, for out of the 150 species of fossils of the Arenig strata only 25 have been found either in beds above or below them. Only 8 genera, comprising 9 species, pass from the Arenigs to the Llandeilo above, and 11 genera, comprising 46 species, which had lived in Tremadoc times, reappear in the Arenig. No less than 40 genera appear for the first time in the Arenig group, and this in itself gives a definite importance to it. Of these there are 16 genera of the Hydrozoa of the Graptolite group. *Didymograptus* (figs. 593, 594), *Callograptus*, *Diplograptus*, and *Tetragraptus* are examples. Four genera of Annelida, *Helminthollithes*, *Stellascolithes*, *Nereites*, and *Palæochorda*, appeared; with the genera of the Trilobita, *Æglina*, *Trinucleus*, *Barrandia*, *Calymene*, *Phacops*, *Placoparia*, *Illænus*, and *Homalonotus*. *Ribeiria* and *Redoina* were new Lamellibranchs, and *Ophileta*, *Pleurotomaria*, *Rhaphistoma*, new genera of Gastropoda. *Orthoceras* occurs, and there are four species of the genus in the Welsh and Shropshire area. The Corals, Bryozoa, and Echinodermata are not represented. Phyllopoda of the genus *Caryocaris* are peculiar to the group, and there are only 18 species of Brachiopoda —the special forms being *Dinobolus Hicksii*, Salt., *Siphonotreta micula*, M'Coy, *Discina* sp., *Orthis striatula*, Emmons, *O. remota*, Salt., and *O. alata*, Sow.

This Arenig group may therefore be conveniently regarded as the base of the Ordovician system; some authors, however, prefer to include in the Ordovician the underlying Tremadoc slates.

Sedgwick noticed that the Arenig dark slates, shales, flags, and bands of sandstone were associated with masses of igneous rock, and it is evident that while the sedimentary strata were accumulating, volcanic action was going on. Hence great thicknesses of felsitic or rhyolitic lavas and tuffs were erupted and spread over the land and the sea-floor, and were interstratified with the fossiliferous sediments. Some of the most important Welsh mountains consist mainly of these volcanic materials— such as Cader Idris, the Arans, Arenig Mountains, and others.

Ordovician Strata of the Lake District.—In this area the Bala and Caradoc are probably represented by the Asgill shales, the Coniston limestone, and the underlying great volcanic series, the Borrowdale. The Arenigs find their equivalents in the Skiddaw slates.

Ordovician Strata of Scotland.—The Ordovician of the Borderland consists of greatly contorted strata, which have been worn and denuded into hills of moderate height, and deep valleys. In the Girvan district there are,

besides conglomerates and metamorphosed rocks, calcareous beds, which represent the Llandovery, Bala, and Llandeilo groups. In the Moffat district there are gritty or coarse-grained greywacké, fissile flagstones, conglomerates, and bands of black carbonaceous shales, with cream-coloured clay and ironstone nodules. The black bands occur in lenticular masses in the greywacké, and, although they cover a vast area, are contorted, often reversed, and highly fossiliferous. Lapworth has shown that there are three horizons at which these black bands occur, and at each is found a profusion of Graptolites. The highest, or Lower Llandovery—the Birkhill shales—contain zones of *Rastrites*, *Monograptus*, and *Diplograptus*, and there is a decided palæontological break between this horizon and the next below, or the Hartfell shales, which are of Bala age, and contain *Dicellograptus*, *Pleurograptus*, and *Climacograptus*. The Glenkiln shales are upper Llandeilo in age, and contain *Didymograptus*. Still older beds, of Arenig age, are found in the Scottish Borderland containing thick beds of chert, in which the researches of Professor Nicholson and Dr. G. J. Hinde have revealed the presence of great numbers of Radiolarians.

Besides the works cited at the end of the last chapter, reference should be made to numerous valuable papers on the Ordovician of Wales by Dr. Hicks, published in the 'Quart. Journ. Geol. Soc.,' vols. xxxi. and xxxii. &c., and to those of Professor Nicholson and Mr. Marr on the rocks of the Lake District, 'Quart. Journ. Geol. Soc.,' vols. xxxiii., xliv. &c.

CHAPTER XXVI

THE CAMBRIAN SYSTEM

Divisions of the Cambrian System—Cambrian Flora and Fauna—Sponges—Graptolites—Echinodermata—Brachiopoda—Mollusca—Annelida—Trilobita—The oldest known fossils of the Lower Cambrian Period—Upper Cambrian, Tremadoc slates and Lingula Flags—Middle Cambrian, Menevian beds, Harlech grits, and Llanberis slates—Lower Cambrian, Comley Sandstone, Cambrian of Scotland, Durness Limestone, Girvan Limestone—'Fucoid'- and Olenellus-beds.

Nomenclature and Classification of the Cambrian strata.—This system of strata, being the oldest in which a marine fauna has been detected, is of the highest interest to the geologist. There is fortunately, now, little difference of opinion as to the name which should be applied to it. Sedgwick proposed the name 'Cambrian' as early as 1835, and it has now come into almost universal use. Barrande, it is true, suggested that the strata should be called 'Primordial,' or 'Primordial Silurian;' but a name which suggests that no earlier fossiliferous rocks will ever be found is clearly objectionable. Marcou and other geologists in America have tried to revive the name Taconic, which was proposed by Emmons in 1842. But there are serious doubts as to how far the strata indicated by that name are identical with the true Cambrian.

During the last few years very important strata have been detected in many different districts which are regarded as constituting the base of the Cambrian; so that the system is now considered to consist of three members, which are named as follows:—

Upper Cambrian: *Olenus* beds.
Middle Cambrian: *Paradoxides* beds.
Lower Cambrian: *Olenellus* beds.

Professor Lapworth has proposed to employ the name of Taconic for the lowest division of the Cambrian, but the suggestion does not appear to have met with any general acceptance.

In America the Lower Cambrian has been called 'Georgian,' the Middle Cambrian 'Acadian,' and the Upper Cambrian 'Potsdamian.'

It must be borne in mind that the older writers, following Murchison, ascribed to the Cambrian all the strata containing unsatisfactory fossils or none at all, and it is only in recent years that the true characteristics of the three great Cambrian faunas have come to be recognised. Many of the strata formerly confounded with the Cambrian, like the Torridonian and the Longmyndian, are now proved to be of pre-Cambrian age.

Characteristics of the Cambrian Fauna and Flora.—This oldest known fauna, although poor in the number of species represented in it, is remarkable for the variety and high organisation of many of the forms of life which it contains. In the British Islands, the Cambrian fossils are usually rare and badly preserved; in most cases the rocks have undergone such an amount of change as to obliterate the traces of organisms, many of the argillaceous beds exhibiting slaty cleavage. The number of species known from the Cambrian of Britain does not probably exceed 200; and in all the European localities taken together the number has been estimated as not exceeding double that amount. The Cambrian fossils are somewhat more numerous and better preserved in North America, and a considerable number of forms have been described; but the known Cambrian species from all parts of the world probably fall below 1,000, which number is small in comparison with that of the fossils found in the Ordovician and the Silurian.

Nevertheless, in spite of this paucity of species in the Cambrian fauna, it is to be noted that in it all the great divisions of the Animal Kingdom are represented except the Vertebrata. The Trilobites, moreover, are of great size, and of by no means lowly organisation. Hence we have no ground whatever for believing that this oldest known fauna is in any proper sense of this term

'primordial,' and represents the beginning of li.e on the globe. If, as all palæontological study indicates, the newer faunas are derived by descent with modification from older ones, then the period preceding the Cambrian Period, during which life flourished on the globe, must probably have been at least as great as that which has elapsed between the Cambrian Period and the present day.

There is another feature of the Cambrian fauna which it is desirable to bear in mind. Even at that early period we find clear indication of a geographical distribution of life-forms. The species of Trilobites, Brachiopoda, &c., found in Britain, Scandinavia, Bohemia, and North America respectively, present general analogies with one another, but are not identical. The great majority of the forms of life found in the Cambrian seem to have been inhabitants of the deep sea, and up to the present time the shallow-water marine forms of the period remain unknown, as do also the freshwater and terrestrial fauna and the terrestrial flora.

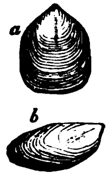
The Cambrian fauna is mainly made up of Brachiopoda and Trilobites, and the representatives of other groups are as a rule by no means abundant.

Traces of marine algæ have been found, and a few Foraminifera and doubtful Radiolarians have been described.

Sponges are represented by *Protospongia* (of which only the spines of the dermal layer are known) and *Archæocyathus*.

Graptolites are comparatively rare in the Cambrian, and are represented by few species; but the curious *Dictyonema* may possibly have been closely related to the group of Rhabdophora (Graptolita).

Fig. 612.



Lingulella Davisii, M'Coy.

a. ½ nat. size.
b. Distorted by cleavage.

Certain markings on the surface of Cambrian rocks have been thought by Nathorst and others to indicate the existence of Medusæ at that early period.

The Echinodermata are only represented by Crinoidea (*Dendrocrinus*), Cystoidea (*Protocystites*), and Starfish (*Palæasterina*).

The Brachiopoda nearly all belong to the division of the Inarticulata, and include the persistent types *Lingula* (*Lingulella*, fig. 612) and *Discina*, with the peculiar genera *Obolus*, *Obolella*, *Acrotreta*, *Acrothele*, *Kutorgina*, &c.

Only a few forms of Lamellibranchiata have been found in the Cambrian, such as *Palæarca* and *Ctenodonta*.

A few Gastropods (*Pleurotomaria*, &c.) occur in the Cambrian.

Many forms of Pteropods, however, are found, including species of *Theca*, or *Hyolithes* (fig. 613).

Cephalopoda are first found in the youngest of the Cambrian strata—the Tremadoc, which are now placed by some authors at the base of the Ordovician. They are represented by *Orthoceras* and *Cyrtoceras* (fig. 614).

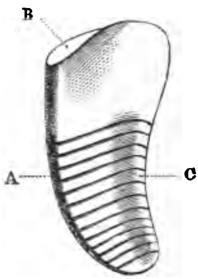
Vermes are represented in the Cambrian by many tracks and burrows, like that known as *Histioderma* (fig. 615).

Fig. 613.

Theca (*Cleidotheca*) *operculata*, Salt., nat. size.

Lower Tremadoc beds, Tremadoc.

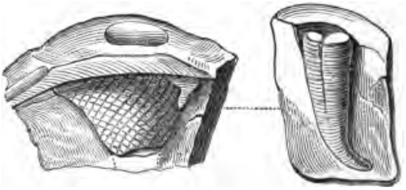
Fig. 614.



Cyrtoceras precox, Salt., mag. Tremadoc rocks, N. Wales.

A. Dorsal edge, place of siphuncle. B. Aperture. C. Ventral edge.

Fig. 615.



1 2

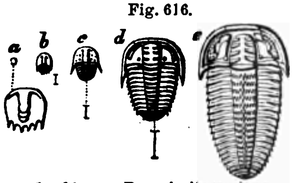
Histioderma hibernica (Kin.). Oldhamia beds. Bray Head, Ireland.

1. Showing opening of burrow, and tube with wrinklings or crossing ridges, probably produced by a tentacled sea worm or annelid.
2. Lower and curved extremity of tube with fine transverse lines.

The Trilobita of the Cambrian are of very great interest. Most of the species appear to have been deep-water forms, and were destitute of eyes. Some of the *Paradoxides* were of great size (more than a foot in length). As was shown by Barrande in the case of *Sao*, the metamorphoses of these early forms can be followed by the study of the fossils. Among the principal genera are *Olenus* (fig. 617), *Conocephalus* (fig. 618), *Micro-*

***discus*, *Ellipsocephalus*, *Sao* (fig. 616), *Dicellocephalus* (fig. 621), *Agnostus* (figs. 619, 620), *Paradoxides* (figs. 622, 623), and *Olenellus*.**

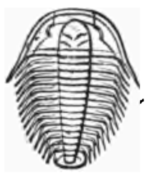
Fig. 616.



Sao hirsuta, Barr., in its various stages of growth.

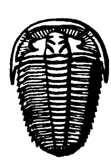
The small lines beneath indicate the true size. In the youngest state, *a*, no segments are visible; as the metamorphosis progresses, *b*, *c*, the body segments, begin to be developed; in the stage *d* the eyes appear, but the facial sutures are not completed; at *e* the full-grown animal. half its true size, is shown.

Fig. 617.



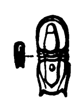
Olenus micrurus, Salter, ½ natural size.

Fig. 618.



Conocoryphe striata (Syn. *Conocephalus striatus*, Emmr.), ½ natural size. Ginetz and Skrey.

Fig. 619.

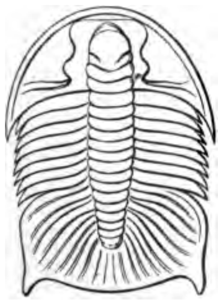


Agnostus integer, Beyr., nat. size and magnified.

Fig. 620.

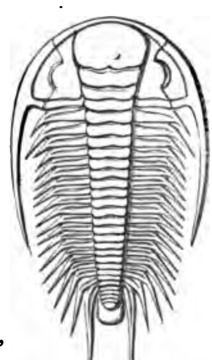
Agnostus Rex, Barr., nat. size. Skrey.

Fig. 621.



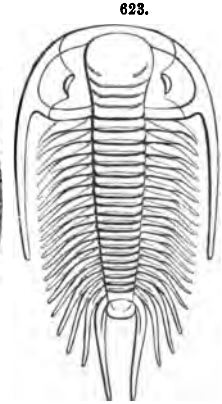
Dikelocephalus minnesotensis, Dale Owen, ½ diameter. A large Trilobite of the Olenoid group. Potsdam Sandstone. Falls of St. Croix, on the Upper Mississippi.

Fig. 622.



Paradoxides bohemicus, Barr., about ½ natural size.

623.

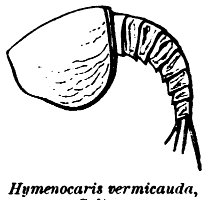


Paradoxides Davidis, Salt., $\frac{1}{10}$ nat. size. Menevian beds, St. David's and Dolgel

Besides the numerous Trilobites, we find other representatives of the Arthropods in several forms of Phyllopods like *Hymenocaris* (fig. 624), and of Ostracods like *Leperditia*.

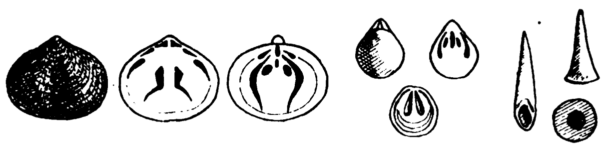
The Oldest known Fossiliferous Rocks.—The lowest Cambrian strata (Taconic of Lapworth, 'Georgian' of American authors) are of great interest to geologists as containing the oldest known marine fauna. This fauna, though small, contains representatives of a considerable number of forms of invertebrate life. Plants (algæ) are doubtfully represented by a number of somewhat obscure impressions. We find the remains of sponges (*Archæocyathus*), possibly of graptolites (*Diplograptus* and *Clinacograptus* ?), and an obscure Cystidean (?). Many Brachiopoda (fig. 625) (*Lingulella*, *Kutorgina*, *Obolella*, &c.), a Lamellibranch (*Fordilla*), some Gastropods (*Platyceras*, *Scenella*, &c.), and many Pteropods (*Hyolithes*, &c.).

Fig. 624.



Hymenocaris vermicauda, Salter.
A Phyllopod Crustacean.
½ natural size.

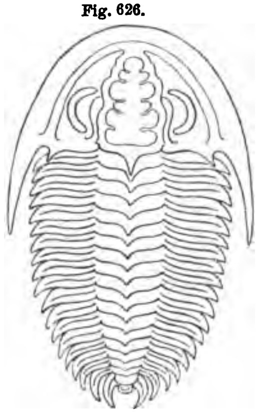
Fig. 625.



a b c

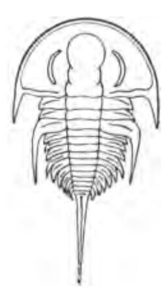
a. Obolella crassa, Hall sp., ½ nat. *b. Lingulella ella*, H. & W., ½ nat. *c. Salterella pulchella*, Bill., ⅜ nat.

Fig. 626.



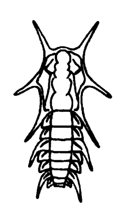
Olenellus Callavei, Lapw., ⅓ nat. From the Comley (Hollybush) Sandstone of Shropshire.

Fig. 627.



Olenellus Lapworthi, Peach, nat. size.

Fig. 628.



Olenellus armatus, Peach, × 2 nat.

From the Lowest Cambrian Strata of N.W. Scotland.

Remains of Annelids (*Salterella*, fig. 625, *c*, &c.) abound in many of the beds, but the most important fossils are the representatives of the Arthropoda. We find an Ostracod (*Leperditia*), a Phyllopod (*Protocaris*), and a number of Trilobita, including *Olenellus* and allied genera (figs. 626–628), and *Agnostus*.

British Representatives of the Cambrian System.—The Cambrian, like the overlying Ordovician, is usually regarded as consisting of three members—the Upper Cambrian, including the Tremadoc slates and Lingula flags; the Middle Cambrian, consisting of the Menevian beds, the Llanberis slates, and the Harlech grits; and the Lower Cambrian, represented by the Hollybush sandstone of Central England and the 'Fucoid beds' of Scotland. The Upper, Middle, and Lower Cambrian are sometimes known respectively as the *Olenus* beds, the *Paradoxides* beds, and the *Olenellus* beds, from the genera of Trilobites which characterise those several divisions.

Upper Cambrian, or strata characterised by *Olenus*. — These consist of a great thickness of strata, among which the following divisions have been established by geologists.

Tremadoc slates.—The Tremadoc slates of Sedgwick are more than 1,000 feet in thickness, and consist of dark earthy grey slates occurring near the little town of Tremadoc, situated on the north side of Cardigan Bay in Caernarvonshire.

They were traced subsequently to Dolgelly, and of late years strata of the same age have been discovered and carefully examined by Dr. Hicks, at St. David's promontory and Ramsey Island, South Wales, where there are dark earthy flags and sandstones 1,000 feet thick, with many fossils. They rest conformably upon thick Lingula flags. Subsequently Mr. Callaway has shown that the Shineton shale of Shropshire is of Lower Tremadoc age. The fauna is very remarkable, and differs considerably in North and South Wales; it contains at least 84 species, and many great groups of the invertebrata appear in the rocks for the first time. The Crinoidea, Asteroidea, and Cephalopoda are represented therein, for the first time in the world's history. There are many new genera of Trilobita, such as *Nesuretus*, *Psilocephalus*, *Niobe*, *Angelina*, *Asaphus*, and *Cheirurus*, besides some which existed in the lower rocks, such as *Agnostus*, *Conocoryphe*, and *Olenus*. The Crinoid *Dendrocrinus* and Asteroid *Palæasterina*, the Cephalopoda *Orthoceras sericeum*, Salt., and *Cyrtoceras præcox*, Salt. (fig. 614), of the Upper Tremadocs, are the first known. The Lamellibranchs *Ctenodonta*, *Palæarca*, *Glyptarca*, *Davidia*, and *Modiolopsis* make their appearance. The Brachiopoda belong to the genera which existed in the underlying strata, and the species *Lingulella Davisii*, M'Coy, and *Orthis Carausii*, Salt., and the genera *Obolella* and *Lingula*, are common to both groups. The North Wales Tremadocs contain 9 species of Pteropoda, principally of the genus *Theca*; and *Bellerophon* is found amongst the Heteropoda. Rhabdophora or graptolites were discovered, in Tremadoc rocks, by Callaway, and belong to the genus *Bryograptus*. Phyllopod Crustacea exist in the Upper Tremadocs, and the characteristic Trilobita are *Angelina Sedgwickii*, Salt., *Asaphus affinis*, McCoy, sp., and an *Olenus*. *Dictyonema sociale*, Salt., and Bryozoa occur, and in the strata below also. By Mr. Marr and some other authors the Tremadoc beds are regarded as forming the base of the Ordovician system, and not the top of the Cambrian.

Lingula flags. — Next below the Tremadoc slates in North Wales, lie micaceous flagstones, bluish and black slates and flags, with bands

of grey flags and sandstones, in which in 1846 Mr. E. Davis discovered the *Lingulella* (fig. 612) named after him, from which was derived the name of Lingula flags. These beds are more than 5,000 feet thick, and have been studied chiefly in the neighbourhood of Dolgelly, Ffestiniog, and Portmadoc in North Wales, and also at St. David's in South Wales. They have yielded 26 genera and 69 species of fossils, of which 9 only are common to the overlying Tremadoc rocks. They include *Dictyonema sociale*, Salt., *Agnostus princeps*, Salt., *Ampyx prænuntius*, Salt., *Conocoryphe depressa*, Salt., *Olenus impar*, Salt., *Lingulella Davisii*, M'Coy, *L. lepis*, Salt., *Obolella*, and *Orthis*. In the Lingula flags *Olenus* (fig. 618), *Agnostus*, *Anopolenus*, *Microdiscus*, *Paradoxides*, and *Conocoryphe* are prominent forms of Trilobita, and *Hymenocaris vermicauda*, Salt. (fig. 624), is a common species of the Phyllopod Crustacea.

The Lingula flags may be divided into two zones, an upper and lower, the middle zone of older authors being of less value. Amongst the fossils of the upper zone is *Dictyonema sociale*, Salt., which occurs at Keys End Hill, Malvern, and in North Wales. No less than 30 species of Crustacea belonging to the genera of Trilobita, just noticed, occur, and only 4 pass up into the Tremadocs. The Brachiopoda are of 8 species, 6 of which pass upwards, and the genera are *Lingula*, *Lingulella*, *Obolella*, *Kutorgina*, and *Orthis*, the two characteristic species being *Lingula pygmæa*, Salt., and *Obolella Salteri*, Hicks. In the Lower Lingula flags, which rest conformably on the Menevian strata, *Cruziana*, a supposed Annelid, occurs, and *Scolioderma* and *Helminthites* are characteristic worms. Nine genera and 25 species of Crustacea are found. *Agnostus limbatus*, Salt., and *A. nodosus*, Salt., *Olenus micrurus*, Salt., *O. gibbosus*, Salt., are peculiar to these lower flags, and so is the Phyllopod *Hymenocaris vermicauda*, Salt. The three genera of Brachiopoda represented are *Lingulella*, *Orthis*, and *Obolella*. Finally, two species of *Theca* occur.

In Merionethshire, according to Sir A. Ramsay, the Lingula flags attain their greatest development; in Caernarvonshire, they thin out so as to have lost two-thirds of their thickness in eleven miles; while in Anglesea and on the Menai Straits, both they and the Tremadoc beds are entirely absent, and the Lower Silurian rocks rest directly on pre-Cambrian strata.

Middle Cambrian, or strata characterised by *Paradoxides*, are also of great thickness. They have been studied in South Wales by Dr. Hicks, who has established the following subdivisions in the series.

Menevian beds.—Immediately beneath the Lingula flags there occurs a series of dark grey and black flags and slates, alternating at the upper part with some beds of sandstone, the whole reaching a thickness of from 500 to 600 feet. These beds were formerly classed, on purely lithological grounds, as the base of the Lingula flags; but Messrs. Hicks and Salter, to whose exertions we owe almost all our knowledge of them, have pointed out that the most characteristic genera found in them are unknown in the Lingula flags, while they possess many forms from the underlying groups of strata. They therefore proposed to place these beds at the top of the Middle Cambrian under the term 'Menevian,' Menevia being the Latin name of St. David's. The beds are well exhibited in the neighbourhood of St. David's in South Wales, and near Dolgelly and Maentwrog in North Wales. They are the equivalents of Étage C of Barrande's Primordial Zone. Fifty-two species have been found in the Menevians, which are very rich in fossils for so early a period. Nineteen species are common to the overlying Lingula flags, but none pass up to the Tremadoc rocks. Twelve genera and 32 species of Trilobita occur, and some forms are of large size; *Paradoxides Davidis*, Salt. (see fig. 628), the largest Trilobite known in Great Britain, nearly 2 feet long, is peculiar to the Menevian. The

other genera are *Agnostus*, *Anopolenus*, *Conocoryphe*, *Holocephalina*; and the special genera of Trilobita are *Arionellus*, *Erinnys*, *Microdiscus*, and *Carausia*.

The Trilobite with the largest number of rings, *Erinnys venulosa*, Salt., occurs here in conjunction with *Agnostus* and *Microdiscus*, the two genera with the smallest number. Blind Trilobites are also found, as well as those which have the largest eyes, such as *Microdiscus* on the one hand, and *Anopolenus* on the other. *Olenus* did not then exist.

The Ostracod *Leperditia* occurs, and the genera *Orthis*, *Discina*, and *Obolella* amongst the Brachiopoda. Several Pteropoda have been found, with the Cystoidean *Protocystites*. Several species of *Protospongia* of the Spongida, and *Arenicolites*, and *Serpulites* amongst the Annelida conclude the fauna. The discovery and description of this remarkable assemblage of early forms, we owe to the careful labour of Dr. Hicks.

Harlech grits and Llanberis slates.—The sandstones of Harlech attain a thickness of no less than 6,000 feet without any interposition of volcanic matter; and in some places in Merionethshire they are still thicker. Until recently these rocks were supposed to contain no fossils. Now, however, through the labours of Dr. Hicks, they have yielded at St. David's a rich fauna of Trilobita, Brachiopoda, Phyllopoda, and Pteropoda, showing, together with other fossils, the existence of a series of by no means low organisms at this very early period. Already the fauna amounts to 29 species, referred to 16 genera; of these, 8 genera and 12 species are common to the Menevian group above, 'a proportion,' says Dr. Hicks, 'far greater than we usually find between two groups so dissimilar in lithological characters and comprising so great a thickness of strata.'

It is one of the many proofs that the early forms of life were less influenced by the struggle for existence, which became severer with time.

A new Trilobite, called *Plutonia Sedgwickii* by Dr. Hicks, has been met with in the Harlech grits of St. David's. It is comparable in size to the large *Paradoxides Davidis*, Salt., before mentioned, has well-developed eyes, and is covered all over with rough tubercles. In the same strata occur other genera of Trilobites, namely, *Conocoryphe*, *Paradoxides*, *Microdiscus*, *Agnostus*, and the Pteropod *Theca* (fig. 613), all represented by species peculiar to the Harlech grits of that area. The sandstones of this formation are often rippled, and were evidently left dry at low tides, so that the surface was dried by the sun and made to shrink and present sun-cracks. There are also distinct impressions of raindrops on the surfaces of many strata. Fossils occur yet earlier in the Harlech group of St. David's in the lower red shales that immediately overlie the conglomerate at the base of the Cambrian formation. The only forms yet found are *Lingulella ferruginea*, Salt., *L. primæva*, Hicks, *Leperditia Cambrensis*, Hicks, and *Discina Caerfaiensis*, Hicks.

The slates of Llanberis and Penrhyn in Caernarvonshire, with their associated sandy strata, attain a great thickness, sometimes about 3,000 feet. They are probably of the same age as the Harlech and Barmouth beds last mentioned, for they may represent the deposits of fine mud thrown down in the same sea, on the borders of which the sands above mentioned were accumulating. The Middle Cambrian age of at least a portion of these strata has been determined by the finding in them of a *Conocoryphe* (*C. Viola*, Woodw.). In South Wales the beds of St. David's with *Lingulella* pass down to a conglomerate, and a similar indication of a physical break is found in North Wales, according to Dr. Hicks and Professor Hughes. Below are rocks the age of which is disputed (p. 457).

Lower Cambrian, or strata characterised by *Olenellus*.—On the flanks of Caer Caradoc in Shropshire, Professor Lapworth

has discovered, in beds known as the Comley sandstone, remains of the Trilobite genus *Olenellus* (fig. 626), with several Brachiopods, which like it are characteristic of the Oldest Cambrian. The higher portions of this sandstone, however, contain *Paradoxides*, and must be referred to the Middle Cambrian.

North-west Scotland succession.—In the North-western Highlands of Scotland are found limestones of Upper Cambrian age. The relation of these strata to those above and below them is now happily settled.

Beneath the limestone are sandy shales and quartzites with Annelid tubes, of *Salterella Maccullochi*, Salt. sp., resting on and overlapping red sandstone, grit and conglomerate (Torridon sandstone), to which a Cambrian age was formerly ascribed, but which are now known to be pre-Cambrian.

Recent discoveries by the Geological Survey have shown that the whole, or nearly the whole, of the strata in the north of Scotland (which were formerly ascribed to the Ordovician, and are of considerable thickness) are really of Cambrian age. The Durness limestone, at the top of the series, contains a remarkable assemblage of fossils, including *Orthoceras* and *Maclurea*, which, as pointed out by Salter, have a very close resemblance to the fauna of the Calciferous sandstone of North America. These strata are probably of the same age as the Tremadoc —that is, they form the top of the Cambrian series, according to the classification now generally accepted by geologists, and they are said in places to attain a thickness of 1,500 feet. Below the limestones there occur sandy beds with worm-burrows (Serpulite grit or *Salterella* grit), and argillaceous beds in which are markings that have been taken to represent seaweeds, and these have been called the fucoid beds. In these 'fucoid beds' the officers of the Geological Survey have detected remains of several species of *Olenellus* (figs. 627, 628), and other fossils of the Lowest Cambrian zone. Beneath the fucoid beds occur thick masses of quartzite perforated by innumerable worm-burrows.

In the Lowlands of Scotland, beneath the series of Ordovician strata, we find at Girvan in Ayrshire beds of limestone containing a somewhat similar fauna to that of the Durness limestone, underlain by a remarkable series of rocks of volcanic origin.

Dr. Hicks's papers on the Cambrian and Ordovician strata have already been referred to, and Dr. Callaway's and Professor Lapworth's accounts of the Cambrian rocks of Shropshire will be found in 'Quart. Journ. Geol. Soc.,' vol. xxxiv., and in the 'Geol. Mag.,' 1888 and 1891. The discovery of the Olenellus fauna in the 'fucoid' beds of the North-west of Scotland is described by Messrs. Peach and Horne, 'Quart. Journ. Geol. Soc.' vols. xlviii. and xlix.

CHAPTER XXVII

FOREIGN DEPOSITS WHICH ARE HOMOTAXIAL WITH THE OLDER PALÆOZOIC STRATA OF THE BRITISH ISLES

Older Palæozoic strata less altered than the British—Basin of Bohemia —'Primordial' strata of Barrande—Stages D, E, F—Older Palæozoic strata of Scandinavia—Olenellus beds—Alum Shales—Limestones and Schists—Russia and other parts of Europe—North America—Geographical distribution of life forms in Cambrian times—Table showing equivalence of strata in different areas.

THE British representatives of the Older Palæozoic rocks, though they are of such great thickness, are usually much altered, especially in their lower portions, and, slaty cleavage having been developed in their fine-grained beds, the fossils are often rendered obscure or altogether obliterated over wide areas. It is a fortunate circumstance that, in other parts of the world, we find strata occupying the same position in the geological series as our Ordovician and Cambrian, but with fossils in a much better state of preservation than in this country.

OLDER PALÆOZOIC STRATA OF EUROPE

Bohemia and Central Europe.—One of the most interesting districts for the study of the Older Paleozoic rocks is Bohemia, where the strata lie in a basin upon the Archæan rocks, and are but little altered. The beds are crowded with fossils in the most admirable state of preservation, and the able French geologist Barrande devoted his life to the collection and description of these ancient and remarkable relics of a number of extinct faunas.

Resting upon crystalline and metamorphic rocks with unfossiliferous schist (the stage A of Barrande) we find a series of Greywackés (stage B of Barrande) which contain traces of Annelids and Brachiopoda, and are believed to represent the Lowest Cambrian (Olenellus zone). Upon these last lie a series of greenish slaty rocks 300 feet in thickness (stage C of Barrande) which have yielded a very rich fauna, that of the Middle Cambrian. These beds were regarded by Barrande as containing the oldest known fauna, and were styled by him 'Primordial beds.' These 'primordial' strata are covered by other argillaceous, sandy, and calcareous beds (the stages D and E of Barrande), D representing the highest Cambrian and Ordovician strata and E the Silurian. The Older Palæozoic rocks of Bohemia, though so rich in fossils, present many local peculiarities, and it is not possible to correlate with absolute precision the minor divisions of the Bohemian rocks with those of our own country.

Barrande entertained the belief that certain assemblages of fossils belonging to the older series of strata may sometimes be found living on in strata of younger age; and for such assemblages of fossils he proposed the name of 'colonies.' Professor Lapworth, Mr. Marr, and other geologists have shown that Barrande's so-called 'colonies' are portions of older strata faulted in among newer beds.

Scandinavia.—The Older Palæozoic rocks of Sweden cover a considerable area, and, though of insignificant thickness in compari-

son with our British strata of the same age, they agree much more closely with our own series, both in the sequence of beds and the types of fossils represented, than do the strata of the same age in Bohemia. The base of the series is formed by thick masses of felspathic sandstone and conglomerate, containing very few fossils except obscure and doubtful impressions of plants. These strata, which are called 'Fucoid Sandstones,' 'Eophyton Sandstones,' and 'Sparagmites,' probably represent, in their lower part at least, the Torridon sandstone, but at their summit we find sandy beds containing the *Olenellus* or Lower Cambrian fauna. The thin argillaceous strata known as Alum shales, which overlie these sands, contain in their lower portion the *Paradoxides* fauna, and in their upper portion the *Olenus* fauna; the highest zone of the Cambrian is represented by beds with *Dictyograpsus*. The Ordovician is represented in Scandinavia by limestones containing *Orthoceras* and *Cystoidea*, covered by shales with graptolites and *Trinucleus*, with many characteristic Trilobites of the Arenig, Llandovery, and Bala groups. The Silurian of Scandinavia is represented by beds of limestone containing *Pentamerus*, and many May-Hill and Wenlock types, covered by a conglomerate and nodular limestone with Ludlow fossils.

In the Baltic Provinces and North Germany occur a series of strata which can be fairly well paralleled with those of Scandinavia. At the top of the Cambrian, we find in Russia a bed of glauconite sand which, though only a few feet thick, contains a very interesting assemblage of fossils, including the 'conodonts,' formerly thought to be teeth of fishes, but now regarded as belonging to annelids, and the internal casts of many species of foraminifera.

Other Parts of Europe.—In the Ardennes, in Normandy and Brittany, in the Pyrenees and the Iberian peninsula, and in the island of Sardinia, we also find many very interesting developments of the Cambrian, Ordovician, and Silurian rocks.

OLDER PALÆOZOIC STRATA OF NORTH AMERICA

North America.—In the North American continent the Lowest Cambrian is represented by shales, quartzites, and limestones containing the *Olenellus* fauna (the Georgia beds of the United States geologists). The Middle Cambrian or *Paradoxides* beds consist of slaty beds 2,000 feet thick, well exposed in New Brunswick, Newfoundland, and various localities in the United States, while the vast masses of 'Potsdam sandstone,' 6,000 feet thick, above these, belong to the highest Cambrian or *Olenus* beds above the Potsdam sandstone. The Calciferous sandstone, which in part at least may represent the Upper Cambrian, has a fauna strikingly like that of our Durness and Girvan limestones. The divisions, known as the Chazy limestones, Trenton limestones, Utica shales, and the Hudson River and Cincinnati groups, are on the same general horizon as our Arenig, Llandeilo, and Bala groups, while the Clinton and Medina sandstones represent our May-Hill beds, the Niagara limestone contains similar fossils to our Wenlock, and the Waterlime and Onondaga salt groups agree generally with our Ludlow beds. It is found, however, that in different parts of the United States these several divisions present remarkable differences in mineral characters and fossils.

If we compare the fossils of the Older Palæozoic strata in the British Islands with those of Scandinavia and Bohemia on the one hand, and with those of the North American continent on the other, we shall find that, while the same or similar genera are represented in the several divisions, the actual species in these several areas are often distinct. It is evident that at this the earliest period

of the earth's history of which we have records of the marine life, a geographical distribution of life-forms similar to that which prevails at the present day must have already existed.

The general parallelism of the deposits in the four typical areas in which the Older Palæozoic rocks have been best studied is illustrated in the following table:—

CORRELATION OF THE OLDER PALÆOZOIC ROCKS IN DIFFERENT AREAS

—	BRITISH ISLES	SCANDINAVIA	BOHEMIA	NORTH AMERICA
SILURIAN	Downton beds and tile-stone.	—	—	Waterlime and Onondaga salt groups
	Ludlow with Aymestry limestone . . .	Gothland limestone	Etage Ee_2	—
	Wenlock and Woolhope beds . . .	Limestones and shales with *Pentamerus*	Etage Ee_1	Niagara limestone
	May-Hill or Llandovery group	—	—	Clinton and Medina sandstones
ORDOVICIAN	Bala or Caradoc group .	*Trinucleus* schists	Etage Dd_5 Etage Dd_4	Cincinnati and Hudson River beds
	Llandeilo beds . . .	Graptolite schists	Etage Dd_3	Trenton limestone
	Arenig or Lower Llandeilo beds . . .	Orthoceras limestone	Etage Dd_2 Etage Dd_1 (part)	Chazy limestones
CAMBRIAN	Tremadoc slates and Lingula flags. (*Olenus* beds)	Alum shales	Etage Dd_1 (part)	Calciferous sandstone
	Menevian beds with Llanberis slates (?) . .	—	Etage C	Potsdam sandstone
	Harlech grits. (*Paradoxides* beds) . .	—	—	*Paradoxides* slates of Newfoundland, New Brunswick, and New England
	Comley sandstones (lower part), and *Olenellus* beds	Sandstones with *Olenellus*	Etage B	Olenellus slates of Georgia

A very accurate account of the foreign strata of Older Palæozoic age is given in De Kayser and Lake's 'Text-book of Comparative Geology.' The whole of the foreign representatives of the lowest Cambrian or Olenellus beds have been described, and their fossils figured, by the Director of the United States' Geological Survey, Mr. C. Walcott. 10th Ann. Rep. U.S. Geol. Survey, (1890).

CHAPTER XXVIII

SEDIMENTARY ROCKS OF PRE-CAMBRIAN AGE

Existence of stratified and other Rock-masses underlying the Older Palæozoic Deposits—Rocks of both Igneous and Aqueous Origin—Obscure Traces of Fossils—Thickness and Extent of pre-Cambrian Rocks—pre-Cambrian strata of the British Isles—Pebidian—Arvonian—Dimetian—Fundamental Gneiss, or Lewisian—Caledonian, or Dalradian—Malvernian—Monian—Uriconian—Longmyndian—The Torridon Sandstone, or Torridonian—Pre-Cambrian of Europe and North America—Huronian—Laurentian, Upper and Lower—Algonkian and Archæan—Pre-Cambrian of India—Traces of Fossils in pre-Cambrian Rocks.

WITH the disappearance of well-marked and clearly recognisable assemblages of fossils, the work of making out a chronological sequence of sedimentary formations comes to an end. Nevertheless the geologist is acquainted with the fact that beneath the rocks containing the oldest Cambrian fauna there lie many others—some evidently of aqueous origin, others no less clearly of igneous origin—nearly all showing traces of having undergone great alterations. From the circumstance that these rocks contain only imperfect, doubtful, or fragmentary remains of fossils, or none at all, it has not been found practicable to arrange them in a definite chronological sequence.

Although the Cambrian fauna is the oldest assemblage of marine forms of life which has been discovered by geologists in the earth's crust, yet there are enormous thicknesses of rocks underlying the beds containing the Cambrian fossils that are certainly of sedimentary origin and of greater age, and in these we some day hope to find definite traces of earlier forms of life. The pre-Cambrian strata are often many thousands of feet in thickness, and include varieties of arenaceous, argillaceous, calcareous, ferruginous, and other deposits similar to those which make up the fossiliferous rocks of the earth's crust, these being more or less intimately associated with igneous and metamorphic rock masses of a highly crystalline character. If we examine the map of the world compiled by Marcou to illustrate the distribution of the various geological formations in the land areas of the globe, it will be found that the areas occupied by the pre-Cambrian strata are nearly equal to those covered by all the fossiliferous rocks of Palæozoic, Mesozoic, and Cainozoic age.

That the Cambrian fauna does not represent the beginning

of life upon the globe all biologists and geologists must agree. That fauna contains representatives of all the great divisions of the animal kingdom except the Vertebrates; and two of the higher groups of the Invertebrata—the Crustacea and Cephalopoda—are represented in the Cambrian fauna by forms of complex organisation. If there has been a gradual evolution and progression of life-forms in the past, it has been argued by many palæontologists that the periods during which life existed upon the globe before the dawn of the Cambrian period must at least equal that which has elapsed between the beginning of the Cambrian and the present day.

The fact that the pre-Cambrian strata contain beds of limestone and graphite has often been adduced as an argument in favour of the view that plants and animals must have existed in those earlier periods of the earth's history, which have as yet yielded no distinct relics of these ancient forms of life in the shape of fossils. It is perfectly true that nearly all the calcareous and carbonaceous rocks found associated with the fossiliferous strata owe their origin to animal- and plant-life; but it must not be forgotten that both calcium carbonate and carbon in the form of graphite may sometimes be produced by the operation of purely chemical and inorganic agencies.

Nothing more strikingly illustrates the great value of palæontological evidence to the geologist than the fact that it has been found impossible—in the absence of the evidence afforded by fossils—to bring into any kind of correlation the various deposits underlying Cambrian strata. Hence all designations applied to such pre-Cambrian deposits have a purely local value.

Various names have been proposed for those rocks which clearly underlie the Cambrian, and are, therefore, older than that system of strata. The older writers spoke of them as Primary or Azoic rocks, but when the discovery of Eozoon suggested the existence of life-forms during these earlier periods they were called Eozoic. In more recent times the names pre-Cambrian and Archæan have been generally applied to them, though the latter term, as we shall see, is now often used in a more restricted sense.

We will first consider the terms applied to these pre-Cambrian strata in the British Islands, and then proceed to discuss the nomenclature of homotaxial rocks in other parts of the globe.

The Cambrian rocks of the British Isles are underlain not only by great thicknesses of sedimentary rocks without recognisable fossils, but by metamorphic and igneous rocks—plutonic and volcanic. It is usual to term all rocks beneath the Cambrian by the names of pre-Cambrian and Archæan.

The discrepancy of opinion re-

garding the geological structure of the North-west Highlands, mentioned on p. 428, will prepare the student for similar diversities of opinion regarding the age of the rocks which underlie the fossiliferous Lower Cambrian of Wales and the equivalent formations elsewhere. The Geological Survey consider that there is no break present, and that the volcanic and metamorphic rocks underlying the fossiliferous strata are really part of one great Cambrian series.

On the other hand, many other geologists consider that they have sufficient evidence to state that there is a great break at the base of the fossiliferous series, a conglomerate existing there which contains the products of the denudation of two, if not three, more ancient groups of rocks. One of these lower groups was volcanic, and the other and older was metamorphic. They (with a third, according to Dr. Hicks) are included under the term pre-Cambrian, but their relations to the North American pre-Cambrian rocks and similar formations in other areas are not determinable.

Dr. Hicks's researches in the St. David's area tend to prove that there is a vast thickness of unfossiliferous rocks beneath the Cambrian conglomerate, which he groups as follows:—

1. *The Pebidian.*—A volcanic series, made up of ejectamenta, more or less stratified, alternating with schistose, metamorphosed clays, and sandstones. Spherulitic felstone, greenish and purplish felspathic breccias, silvery-white schists, purple shales, light-green clay slates, greenish, reddish, and purplish indurated ashes, often conglomeratic, are found, and also contemporaneous rhyolytic lavas in the form of felstone. The upper beds are red and purple ashy schists. The Pebidian series rests unconformably on the next group, and has a different structure from the overlying Cambrian, to the basal conglomerate of which it contributes pebbles. The upper rocks are mostly basic in character.

2. *The Arvonian* consists of breccias, hälleflintas, quartz felsites, and of rhyolites. Dr. Hicks states that this series rests unconformably on the underlying Dimetian. Some authors, who accept the Dimetian and Pebidian formations of Dr. Hicks, find themselves unable to recognise his Arvonian as a distinct formation.

3. *The Dimetian.*—These lowest rocks, the base of which has not been seen, form an anticlinal axis, flanked by the Pebidian, and partly by unaltered Cambrian strata. The Dimetian rocks are quartz porphyries, often with doubly pyramidal and sub-angular phenocrysts of quartz, and crystals of felspar, in a matrix of grey or green felspathic material. Fine-grained quartz-felsites, ashy, shale-like rocks, with more or less distinct lines of lamination, occur, and compact granitoid rocks, without mica, and with quartz in excess over the orthoclase felspar. Granitoid gneiss, with quartziferous breccias and schists, and quartzites are present. These rocks contribute to the conglomerate at the base of the Cambrian, and were metamorphosed before their denudation occurred.

Professor Bonney has shown that a quartz-felsite, or ancient igneous flow, closely resembling more modern rhyolites, underlies the Cambrian conglomerate in North-west Caernarvonshire. And both he and Dr. Hicks have proved the occurrence of a pre-Cambrian series in Anglesea greatly resembling that of South Wales.

The oldest rock in Scotland is that called by Sir R. Murchison 'the fundamental gneiss,' which is found in the north-west of Ross-shire and in Sutherlandshire, and forms nearly the whole of the adjoining island of the Lewis, in the Hebrides. It has a strike from north-west to south-east, nearly at right angles to the metamorphic strata of the Grampians. On this fundamental, Hebridean or Lewisian gneiss, in parts of the Western Highlands, rocks of doubtful age rest unconformably. These rocks have been called Caledonian by Dr. Callaway, and Dalradian by Sir Archibald Geikie.

The central axis of the Malvern chain consists of hornblendic gneisses and contorted schists, on which rest, unconformably, sandstones of Cambrian age. Many years since, Dr. Holl noted these rocks as being of pre-Cambrian age, and later authors have called them Malvernian.

Professor Blake considers that these older rocks of Anglesea, with some fossiliferous strata referred by other geologists to the Older Palæozoic, constitute a great pre-Cambrian system which he calls the Monian. Dr. Callaway thinks that the patches of ancient rhyolitic lavas and other igneous masses about the Wrekin and adjoining districts in Shropshire are of pre-Cambrian age and constitute a system which he proposes to call the Uriconian. The great mass of slates and slaty flagstones, constituting the mountainous tract of the Longmynd in Shropshire, which was formerly considered as lying at the base of the Cambrian, is now recognised as being of pre-Cambrian age, and has been called by Dr. Callaway the Longmyndian. In the absence of fossils in these various formations the task of correlating the Lewisian, Dimetian, Caledonian, or Dalradian, the Arvonian, Pebidian, Monian, Uriconian, and Longmyndian series, is a hopeless one. It may even be doubted if among these systems there are not some metamorphosed rocks of Palæozoic age.

The Torridon Sandstone or *Torridonian.*—This great system of strata, occurring in the North-West of Scotland and some of the islands of the Hebrides, was first described by Dr. Macculloch in 1819; he showed, in opposition to the views of Murchison and Sedgwick, that it is distinct from the Old Red Sandstone of Scotland, which it somewhat resembles, and that it underlies the strata containing what are now known to be Cambrian fossils. The Torridon strata now occupy a comparatively small area, but the patches which have escaped denudation are evidently portions of what was once a great and widely spread system of strata. The rocks show but little signs of alteration, and consist of strata of white, pink, and purplish-red sandstones, often containing pebbles and passing into conglomerates. Both in the upper and lower portions of the series, bands of dark grey argillaceous rocks are found which have yielded what appear to be tracks and burrows of Annelids, but, up to the present time, no more definite traces of organisms. The thickness of this series of unaltered strata is estimated by the Geological Survey to be no less than 8,000 to 10,000 feet, and that they are older than the Cambrian is shown by the fact that strata containing the characteristic oldest Cambrian fauna, with a number of species of *Olenellus*, are found unconformably overlying them. That an enormous period of time must have elapsed between the deposition of the great mass of unaltered Torridonian strata and the overlying Cambrian is shown by the great unconformity and overlap existing between them, the Cambrian strata being found lying on every portion of the Torridonian series, and passing transgressively from it to the Archæan or fundamental gneiss.

The general relations to one another of these oldest rocks of the British Islands is shown in the sections on the next page (figs. 629–31).

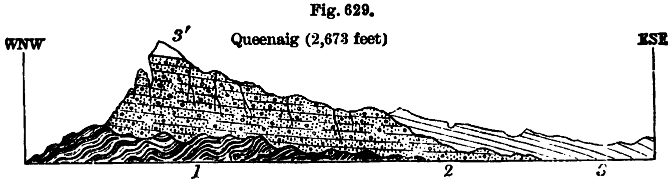
European pre-Cambrian Formations.—On the Continent of Europe it was the custom—as in this country—until comparatively recent years, to group all strata of clearly sedimentary origin with the Cambrian, and to restrict the names pre-Cambrian and Archæan to highly crystalline rocks. But it is now clearly recognised that in such deposits as the felspathic sandstones and conglomerates of Brittany, the Obermittweida conglomerates and similar deposits of Central Germany, and analogous strata in Scandinavia, we have masses of sedimentary rocks, often of great thickness, containing only very obscure traces of organisms and underlying the whole series of Palæozoic rocks; yet these strata lie on, and are evidently younger than, the great masses of granite, gneisses, and

schists—pebbles and fragments of which are frequently included in the stratified masses.

American pre-Cambrian Formations.—In the North American Continent the first attempts to classify the pre-Cambrian deposits were made by Sir William Logan and his colleagues on the Canadian Geological Survey. These observers recognised the fact that beneath the Palæozoic rocks of Canada there occur series of comparatively unaltered sedimentary deposits without fossils, to which they gave the name of Huronian, and that these rest upon and include fragments of a great series of crystalline rocks, granites, gneisses, and schists.

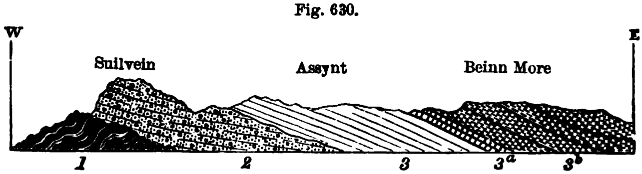
Huronian series.—The strata called Huronian by Sir W. Logan consist chiefly of a quartzite with great masses of greenish chloritic slate. Limestones are rare in this series, but one band of 300 feet in thickness has been traced for considerable distances to the north of Lake Huron. No organic remains have yet been found in any of the beds, which are about 18,000 feet thick, and rest unconformably on the Laurentian rocks.

Fig. 629.



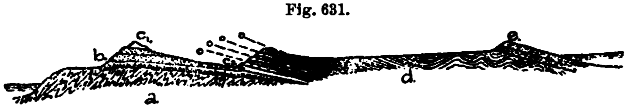
Section near Inchuadamff, Sutherland (after Murchison).
1. Fundamental or Lewisian gneiss of Murchison (Archæan).
2. Torridon Sandstone resting unconformably on 1.
3′. Quartzite of Cambrian age resting unconformably upon 2.
3. Metamorphosed rocks (Caledonian of Callaway, Dalradian of Geikie), thrown by the action of great reversed faults over 1, 2, and 3′.

Fig. 630.



Section across Suilvein and Beinn More, Sutherland.
1. Fundamental or Lewisian gneiss of Murchison (Archæan).
2. Torridon sandstones resting unconformably on 1.
3. Quartzites and (3*a*) limestones full of annelid burrows, and containing a rich Cambrian fauna.
3*b*. Metamorphosed rocks, gneisses and schists (the Caledonian of Callaway and Dalradian of Geikie) faulted over the Cambrian, Torridonian, and Archæan rocks.

Fig. 631.



The same sections as interpreted by Nicol and Lapworth.
a. Fundamental Gneiss. *b.* Torridonian. *c.* Cambrian. *d.* Upper Gneiss forced over the older rocks by great reversed faults (thrusts) *o, o, o, o.* *e.* Old Red Sandstone.

Laurentian group.—Under-

lying the Huronian, northward of the river St. Lawrence, there is a vast series of crystalline rocks of gneiss, mica-schist, quartzite, and limestone, more than 30,000 feet in thickness, which have been called Laurentian, and which are already known to occupy an area of about 200,000 square miles. They had undergone great disturbing movements before the Potsdam sandstone and the other 'primordial' or Cambrian rocks were formed. The newer portion of the Laurentian series is unconformable to the older.

Upper Laurentian, Norian, or Labrador series.—The Upper Group, more than 10,000 feet thick, consists of metamorphic crystalline rocks in which no organic remains have yet been found. They consist of gneisses and granitoid rocks with Labradorite and Anorthite felspars. There are also crystalline limestones and quartzites. These felspathic rocks sometimes form mountain masses almost without any admixture of other minerals; but at other times they include augite, hornblende, and hypersthene. The iridescent felspar, Labradorite, is found in Labrador. These rocks cover a great area in the Adirondack Mountains.

Lower Laurentian.—This formation, about 20,000 feet in thickness, is, as before stated, unconformable to that last mentioned; it consists in great part of massive gneiss of a reddish tint with orthoclase felspar. Beds of nearly pure quartzite, from 400 to 600 feet thick, occur in some places. Hornblendic and micaceous schists are often interstratified, and beds of limestone usually crystalline. Beds of graphite (plumbago) also occur, and it has naturally been conjectured that this pure carbon may have been of organic origin before it underwent metamorphism.

There are several of these limestones which have been traced to great distances, and one of them is from 700 to 1,500 feet thick. In the most massive of them Sir W. Logan observed in 1859 what he considered to be an organic body. It had been obtained the year before by Mr. J. McCulloch at the Grand Calumet on the river Ottawa. This supposed fossil, to which the name of *Eozoon canadense*, Daws., was given, has now, however, been shown to be of inorganic origin (see p. 74).

The geologists of the United States Geological Survey, especially the late Professor R. D. Irving and Mr. C. R. van Hise, have by their studies thrown much new light on the nature and classification of the pre-Cambrian rocks. They recognise that under the Cambrian strata of the North American continent two great series of rocks, each many thousands of feet in thickness and covering vast areas, may be traced. The older series consist of highly crystalline rocks, granites and norites, gneisses and schists, with occasional crystalline limestones and beds of graphite, and it is to these highly crystalline rocks that the American geologists propose to restrict the term Archæan. Between the Cambrian and the Archæan there exist vast thicknesses of strata, sometimes but little altered, at other times displaying clear evidence of considerable metamorphic action, and only exhibiting few and almost indeterminable traces of organisms. These strata the American geologists propose to call Algonkian, and as alternative names they have proposed 'Eparchian' (lying on the Archæan), 'Agnotozoic' (containing unknown forms of life), and 'Proterozoic' (containing the earliest forms of life). It should be noted, however, that the term Proterozoic has been already applied by Professor Lapworth to the faunas which we have called the Older Palæozoic.

Among the Algonkian groups of strata, the United States geologists include the Huronian of Logan and a series of strata which, in the Lake Superior region, appear to lie unconformably upon the Huronian, and have been called the Keweenawan; other groups which apparently underlie the Huronian have received the not very euphonious names of Animike, Keewatin, and Coutchiking; and similar terms have been applied to locally developed pre-Cambrian de-

posits in other parts of the North American continent.

The relics of living beings in the pre-Cambrian stratified rocks (Algonkian or Agnotozoic of American authors) are of a very fragmentary and often doubtful character. Besides the obscure annelid markings found in our own Torridonian fragments, fossils doubtfully referred by Walcott to Lingula, Discina, Hyolithes, and Stromatopora, with traces of Trilobites, have been found in pre-Cambrian strata of the Grand Cañon of the Colorado. In Minnesota a Lingula-like shell has been found in beds of similar age, and tracks of organic origin, with other obscure indications of living beings, have been found in pre-Cambrian strata near Lake Superior and in Newfoundland.

In India, geologists have given the names of the Gwalior system, the Dhárwár system, the Bijáwar system, the Arávalli system, the Cuddapah system, and the older Vindhyan system to masses of more or less altered beds, containing scarcely any traces of organisms, which in some cases can be shown to underlie the Palæozoic rocks.

Noetling has recently described a series of strata as underlying beds containing *Olenellus* in North-West India. He confirms the conclusions of Waagen that this series of strata, containing fossils, named by the latter as *Neobolus Warthi*, *N. Wynnei* and *Hyolithus Wynnei* with *Stenotheca*, and various remains of Annelida, is really of older age than the Lowest Cambrian with Olenellus. If these conclusions be substantiated, we have probably indications in this district of a new system of fossiliferous strata of greater antiquity than the Cambrian.

In Brittany, Barrois and Cayeux have described the pre-Cambrian rocks of that county as containing great numbers of shells of Radiolarians, Foraminifera, and Sponges. If the organisms they have described as belonging to these groups are rightly referred to those three divisions of the animal kingdom, it is remarkable that the oldest Protozoa and Sponges were of much smaller dimensions than those of the Palæozoic and overlying rocks. Future discoveries may, it is hoped, lift the veil of mystery which still envelopes the life-history of the oldest known sedimentary rocks of the earth's crust.

The pre-Cambrian strata of Great Britain will be found described in detail, and their relations discussed, in Papers in the 'Quart. Journ. Geol. Soc.' by Dr. Hicks, Dr. Callaway, and Professor Blake. The relations of the Cambrian and pre-Cambrian strata of the North-west of Scotland to one another were long the subject of controversy, and papers on the subject will be found in the same journal by Sir R. Murchison, Prof. Nicol, Sir A. Geikie, Sir A. Ramsay, Prof. Harkness, Dr. Hicks, Dr. Callaway, Prof. Bonney, Messrs. Peach and Horne. For a summary of the various opinions put forward by different authors the student is referred to a paper by Mr. Hudleston, 'Proc. Geol. Assoc.,' 1878, and to the Address to the Geological Section of the British Association at Aberdeen, 1885. See also Prof. Lapworth's 'Secret of the Highlands,' 'Geol. Mag.,' 1883.

CHAPTER XXIX

GENERAL REVIEW OF THE SUCCESSION AND CHARACTERS OF THE SEDIMENTARY ROCKS

Fossils not found uniformly distributed in Sedimentary Formations—Imperfection of our Knowledge of Freshwater and Terrestrial Conditions during past Geological Times—Existence of Organisms before Cambrian Times—Illustrations of the great Imperfection of the Geological Record—'Time-ratios' of the Geological Eras—Date of Appearance of different Forms of Life as modified by new Discoveries of Fossils—General Order in which Life-forms have appeared upon the Earth—Groups of Animals and Plants which have predominated in successive Periods—Synthetic Types—Specialised Types—Persistent Types—Summary of Palæontological History—Table of Fossiliferous Sedimentary Formations.

Variations in the Number of Fossils found in different Formations.—It will be seen from the foregoing chapters that as we go backwards in time the records of the changes which have taken place, both in the earth's crust and in the animals and plants which have inhabited it, become more and more fragmentary and obscure. In this respect the history of the earth resembles that of the human race.

Marine Strata more frequently preserved than Freshwater or Terrestrial Deposits.—The Cainozoic strata include deposits of marine, freshwater, and terrestrial origin, and the forms of vegetable and animal life which existed while these strata were being deposited are almost as well known to us as those of the present day. In the case of the plants and Invertebrata, most of the Cainozoic fossils can be referred to existing genera. The Vertebrata of the Cainozoic, however, differ greatly from existing forms, and the farther we go back in the Tertiary series, the more remarkable and anomalous are the forms of mammalian and reptilian life which are found in the strata, while the actual proportion of invertebrate forms still living steadily diminishes. But while it is true that the younger strata are, as a general rule, much more highly fossiliferous than the older ones, there are many exceptions to this rule. Formations containing beds of limestone, like the Carboniferous and Jurassic, may yield many more fossils than those in which calcareous beds are wanting. It can be shown, in innumerable cases, that strata which must once have been crowded with fossils now exhibit only few and obscure traces of organisms.

Between the Tertiary and Cretaceous strata we have evidence of a very great break; for in the Cretaceous system almost

every one of the Tertiary species is seen to be absent, and in the place of the familiar types of plants and animals we find wonderful assemblages of strange and curious forms. In the Jurassic and the Triassic almost all the forms that inhabited the seas are different from those of the Cretaceous and from one another. Although the Mesozoic systems contain some intercalated strata of freshwater origin, yet only few and imperfect traces of the terrestrial life of those vast periods remain for our study.

The Newer-Palæozoic rocks still exhibit alternations of marine and freshwater strata; but the marine faunas and floras are far better known than the freshwater one. In the Coal-measures we are presented with the earliest important record of a terrestrial flora. When we reach the Older-Palæozoic rocks, all relics of freshwater and terrestrial life are wanting, though marine forms of life are well represented. In passing from the Silurian to the Ordovician, and from the latter to the Cambrian, the number and variety of the marine types rapidly diminish, though in the earliest of the Cambrian faunas all the great groups of invertebrate life are still represented. The terrestrial flora of Older Palæozoic times is practically unknown to us.

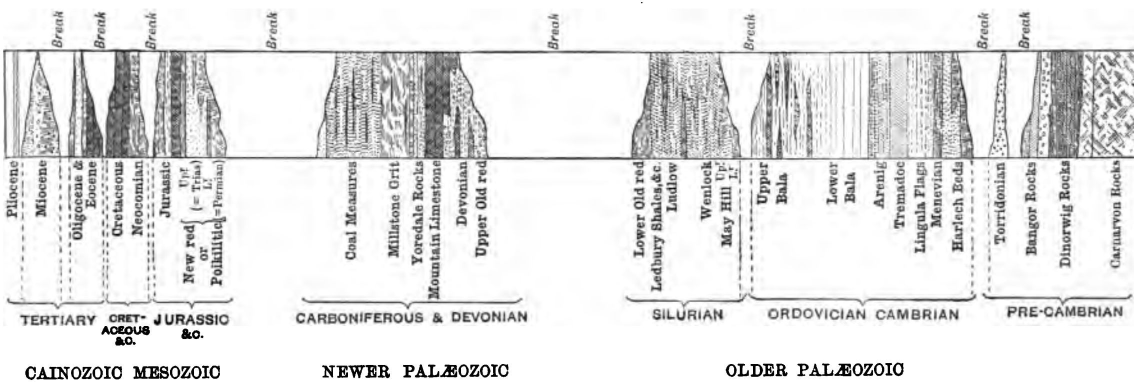
Existence of living Beings before the Cambrian Period. The pre-Cambrian stratified rocks include masses of sediments, which may not improbably rival in thickness the whole of the fossiliferous formations. Yet the only forms of life as yet detected in them are a number of very minute Protozoa (Radiolarians and Foraminifera), with some Brachiopoda and Pteropoda and obscure tracks and markings, indicative of the existence of other forms of life, but not sufficiently definite to reveal the real nature and character of the organisms. Judging from the nature and degree of development of the oldest known Cambrian fossils, periods of time must have elapsed between the first appearance of life on the globe and the commencement of the Cambrian Epoch, at least as vast as those which separate the Cambrian fauna from that of the present day.

Imperfection of the Geological Record.—We have seen that the series of stratified rocks must not be looked upon as containing a complete and unbroken series of records of the earth's past history. In many cases, indeed, the gaps in the succession of strata must represent periods of time of vaster duration than those represented by the thickest masses of strata themselves.

Dr. R. D. Roberts has endeavoured to give some idea of the fact that the geological record in our islands is a most imperfect and fragmentary one. In the adjoining woodcut, taken from

Diagram showing Thicknesses of Stratified Deposits in Europe with Breaks in the Series. *Scale 1 inch = 16,000 feet.*

In this diagram an attempt has been made to illustrate the fragmentary character of the Geological Record, even in the British Islands, where the series of formations is exceptionally well represented. Where thick strata occur on the continent of Europe in the place of thinner deposits or entire gaps in the series, the fact has been indicated by an expansion of beds on the left-hand side of the column. But no attempt has been made to introduce any intermediate deposits from other parts of the globe. The relative spaces assigned to the several breaks are of course hypothetical; some are certainly too small, others may be too large; but the general relations between the thicknesses of the formations and the gaps between them—both representing vast periods of time—are probably fairly represented in the diagram.



his work, an attempt is made to illustrate the vastness of the gaps which must separate the fragmentary masses of sediment in the British Islands.

Mr. Darwin has justly said: 'The crust of the earth, with its embedded remains, must not be looked at as a well-filled museum, but as a poor collection made at hazard and at rare intervals. The accumulation of each fossiliferous formation will be recognised as having depended on an unusual concurrence of favourable circumstances, and the blank intervals between the successive stages as having been of vast duration. But we shall be able to gauge with some security the duration of these intervals by a comparison of the preceding and succeeding organic forms. We must be cautious in attempting to correlate, as strictly contemporaneous, two formations, which do not include many identical species, by the general succession of the forms of life. As species are produced and exterminated by slowly acting and still existing causes, and not by miraculous acts of creation; and as the most important of all causes of organic change is one which is almost independent of altered, and perhaps suddenly altered, physical conditions, namely, the mutual relation of organism to organism—the improvement of one organism entailing the improvement or the extermination of others; it follows that the amount of organic change in the fossils of consecutive formations probably serves as a fair measure of the relative, though not actual, lapse of time.'

If we bear in mind how small must be the proportion of the relics of plants and animals, now existing, that have any chance of being buried and preserved in the accumulations now being formed in seas and lakes; if we consider how remarkable must be the combination of circumstances conducing to the mineralisation of those relics, and their preservation to a remote antiquity; and if we reflect upon the remoteness of the probability of organisms, when buried and preserved by fossilisation, being exposed at the surface and found by man—we shall be on our guard against regarding the thousands and hundreds of thousands of beautiful fossils which are displayed in our museums, as representing more than a very small fraction indeed of the forms of life that have once existed on the globe.

To conceive of the actual condition of our geological record, as has been well pointed out, we must regard it, not as a fully written history, in many orderly ranged volumes, but rather as what would remain of such a history if all the earlier volumes—constituting at least half the series—were destroyed, while of the remainder, whole chapters were torn out and innumerable pages hopelessly defaced. To deal with such historical materials

as if they were complete and consecutive can lead only to misconceptions and erroneous conclusions. But, treated judiciously, such materials—imperfect and fragmentary though they be—may teach us much that is of value concerning the past. The geological record, though it be incomplete, nevertheless affords us a number of glimpses into the past history of the globe, and it supplies us with invaluable relics of the wonderful physical changes and of the succession of plants and animals that have flourished in bygone times.

In the table at the end of this chapter we have brought together, as nearly as possible in consecutive order, the various sedimentary deposits described in the foregoing pages; and these will be seen to constitute a grand, if far from complete, history of the earth during long past ages.

Relative Duration of the several Geological Periods.—Attempts have been made to estimate the relative lengths of the periods of time required for the accumulation of the great masses of fossiliferous strata of the earth's crust. Whether we consider the thicknesses of the strata deposited during each of the geological periods, or the changes which occurred in the life of each period, and in the intervals between the deposition of the various systems of strata, the time required must have been almost inconceivably great. The late Professor J. D. Dana estimated that the thicknesses of strata deposited in successive geological periods is such as to require us to believe that the Mesozoic era must have had three times the duration of the Cainozoic; the Newer-Palæozoic era, he believed, must have been of considerably greater duration than the Mesozoic; while the Older-Palæozoic era, he considered, must have been twice as long as the Newer-Palæozoic. If we divide the time during which the sedimentary and fossiliferous rocks were deposited into sixteen equal parts, these, according to Dana, would have to be assigned as follows:—

Cainozoic Era, 1
Mesozoic Era, 3
Newer-Palæozoic Era, 4
Older-Palæozoic Era, 8.

The study of the changes which have taken place in the various forms of life during these several eras leads us to infer that this rough estimate may not be very far from the truth.

Order of Appearance of different Forms of Life.—It by no means follows that the deposit in which the remains of an organism, or of a particular class of organisms, is first found, marks the period at which the organism, or class, appeared on

the earth's surface. On the contrary, it is reasonable to conclude that the chances of an organism, or class of organisms, being preserved in a stratum must be very small indeed until the particular forms of life become abundant and widely diffused. Hence, as was shown in the earlier editions of this work, the progress of discovery has continually led to the putting back in time of the date of appearance of different groups of animals and plants. We may recall these facts by reproducing the following table relating to the Vertebrata:—

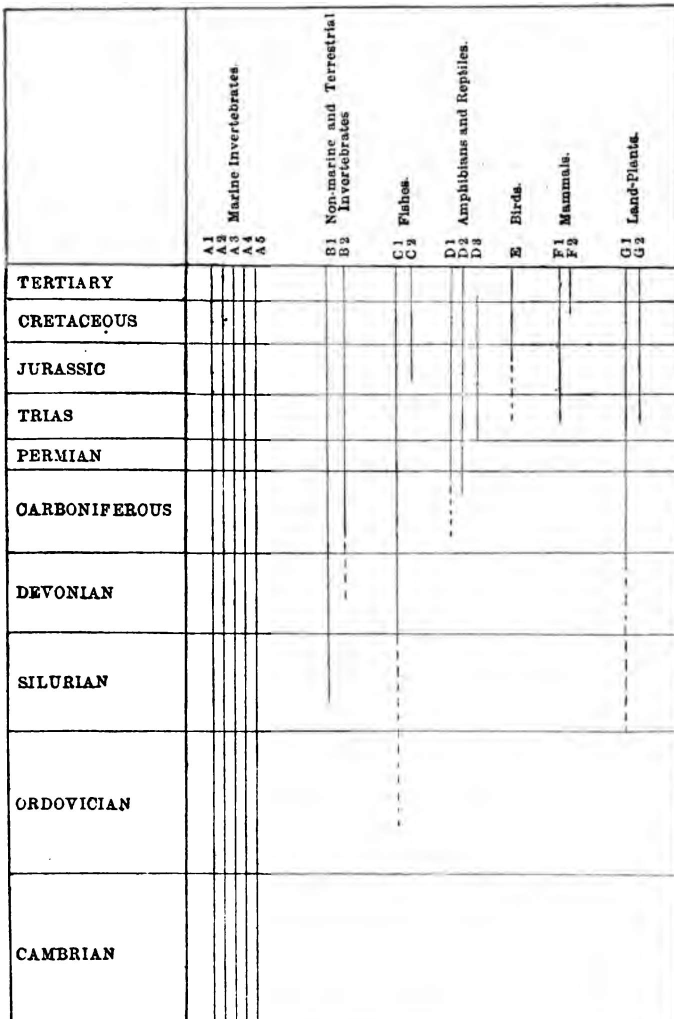
Dates of the Discovery of different Classes of Fossil Vertebrata, showing the gradual progress made in tracing them to rocks of higher antiquity.

Class	Year	Formation	Localities
Mammalia	1798	Oligocene	Paris
	1818	Lower Oolite	Stonesfield
	1847	Rhætic	Stuttgart
	1884	Trias	South Africa
Aves	1839	Lower Eocene	Isle of Sheppey
	1854	" "	London
	1858	Upper Greensand	Cambridge
	1863	Upper Oolite	Solenhofen
Reptilia and Amphibia	1810	Permian	Thuringia
	1844	Carboniferous	Saarbrück
Pisces	1709	Permian	Thuringia
	1793	Carboniferous	Glasgow
	1828	Devonian	Caithness
	1840	Upper Ludlow	Ludlow
	1859	Lower Ludlow	Leintwardine
	1895	Wenlock	Sweden
	—	(?) Ordovician	California

In the table on the opposite page, which is based on one recently published by the eminent American palæontologist, Dr. C. A. White, the order of appearance of the principal groups of animals and plants is indicated. In representing approximately the thickness of the systems of strata and the duration of the several geological periods, the 'time-ratios' calculated by Prof. J. D. Dana have been employed.

All the great groups of the Invertebrata, the Protozoa, the Cœlenterata, the Echinodermata, the Arthropoda, and the Mollusca had come into existence and acquired their distinctive characters in the Cambrian periods. During successive periods each of these groups underwent a wonderful series of changes, the direction of those changes being in almost every case from forms in which we find a blending of character now exhibited by different groups ('generalised' or 'synthetic' types)—which

RANGE OF ANIMALS AND PLANTS IN GEOLOGICAL TIME



A 1 Protozoa A 2 Cœlenterata A 3 Echinodermata A 4 Arthropoda A 5 Mollusca (with Molluscoida) B 1 Insects B 2 Terrestrial and Fresh-water Mollusca C 1 Fish C 2 Teleosteans D 1 Amphibians D 2 Reptiles D 3 Dinosaurs E Birds F 1 Non-placental Mammals F 2 Placental Mammals G 1 Plants G 2 Dicotyledons and Palms

abounded in earlier periods of the earth's history—to those forms in which these characters are found separated from one another in distinct species or genera ('specialised types'). While many of the forms of life show such remarkable and constant changes, others (like *Nautilus* and *Lingula*) lived on through the geological periods with but little change, and these we speak of as 'persistent types.'

Although new discoveries may modify our views concerning the exact period at which certain groups of the Vertebrata made their appearance on the earth's surface, as shown in the table, it is not likely that any new facts which may be learnt by future research will seriously modify our conclusions concerning the *order* of those appearances. There is clear evidence that the general rate of change among the Vertebrates was more rapid than in the case of the Invertebrates; and in the higher Vertebrates (Mammalia and Aves) it was more rapid than in the lower ones (Reptilia, Amphibia, and Pisces). Among the Vertebrates, as among the Invertebrates, we find remarkable synthetic or generalised types constituting the earlier representatives of each group, and these are followed by more specialised forms, gradually approximating in structure to those which are now living. A few Vertebrates, like *Ceratodus* among the fishes and the Rhyncocephalians among the reptiles, may be considered to be persistent types.

Predominance of certain Types of Animal and Vegetable Life at particular Periods of the Earth's History.—Although doubt must always exist as to the exact time of the appearance on the earth of particular forms of life, nothing can be more certain than the fact that during successive periods of the earth's history different groups of animals and plants attained a wonderful development, and characterised the epoch by their numbers and variety of forms. It is equally clear that the dominant types of each succeeding period belong to groups of higher and higher organisation. The Older Palæozoic rocks yield few forms of life, except those of the Invertebrata, and among these the Graptolites, the Brachiopoda (especially curious inarticulate forms)—which altogether outnumber the rare Lamellibranchiata—and the remarkable Trilobita are especially conspicuous. In the Newer Palæozoic period we find the Corals, Echinodermata, the articulate Brachiopoda, with the anomalous Stromatoporoidea and Monticuliporida, existing in great numbers. The Graptolites have disappeared, and the declining Trilobita are replaced by forms of the Eurypterida, the Xiphosura, and Crustaceans. The Cystoidea are replaced by the Blastoidea, while the Crinoidea and other groups of the

Echinodermata attain a very striking development. What is a most remarkable fact, however, about the life of the Newer Palæozoic era, is the abundance and variety of the forms of fishes of that early period, while the closely related Amphibians also make their first appearance. The Mesozoic era is distinguished by the appearance of many Sponges, Corals, and Echinodermata much more closely related in their structure to those of living forms than are those of Palæozoic times. The Brachiopoda lose their overwhelming predominance, and many living genera of Lamellibranchiata and Gastropoda make their appearance in great numbers. The most noteworthy peculiarity of the Mesozoic era, however, is the profusion and variety of the forms of life known as Ammonites and Belemnites, and the replacement of the Palæozoic Arthropoda (Trilobita and Eurypterida) by forms not very dissimilar to those which now exist. Among the Vertebrata, Fish and Amphibians lose their predominance, and the Reptilia acquire a wonderful development. Instead of the four or five orders of the present day, we find the Reptilia represented by nearly twenty orders (see Appendix C.), and the reptiles of the period are remarkable alike for their singularity and variety of form, and for the enormous dimensions which they attained. Among the Reptilia were singular bird-like forms (Dinosauria) and equally remarkable mammal-like types (Theriodontia); but true birds and mammals—all apparently belonging to lowly and synthetic types—made their appearance during Mesozoic times. The Mesozoic was the 'Age of Reptiles;' the Cainozoic 'the Age of Mammals.' As the Mesozoic reptiles of aberrant forms disappeared, the mammalia —in great numbers and often of vast size—came into existence. The earliest forms were synthetic types, but, as we trace them through succeeding periods, the specialised types (like camels, horses, and elephants) appear, and gradually acquire their distinctive and peculiar characters. The Invertebrata of the Mesozoic era differ far less from those of the present day than do the Vertebrata. Ammonites and Belemnites disappear, the Brachiopoda decline in numbers and become subordinate to the Lamellibranchiata, and the existing genera and species appear in ever-increasing numbers, as we follow the succession of the Tertiary strata.

What is true of the animal life of past ages is equally true of the plant life. Of the marine algæ—excepting those rare forms which have a calcareous skeleton—our knowledge is necessarily limited. The oldest terrestrial flora known is that of the Newer Palæozoic rocks. Making every allowance for the fact that the remains of plants found are usually those growing in

marshy situations, and that hence they may not fairly represent the entire plant-life of the period, the Carboniferous flora is a very remarkable one. The abundance and enormous size of the Cryptogams are very striking phenomena; and still more wonderful is the fact that at this early period these Cryptogams, whether allied to the recent Filices, Lycopodiaceæ, or Equisetaceæ, all exhibit the exogenous mode of growth now found almost alone in the Phanerogamous plants. The Cycads and Conifers, and curious forms possibly intermediate between them and the Cryptogams, which existed in considerable numbers in Newer Palæozoic times, became still more abundant, and constituted the dominant forms of vegetation in the Mesozoic era. But during the Cretaceous we witness the incoming of the existing flora, Cryptogams and Gymosperms declining in numbers and size, and being replaced by the Angiosperms, both Monocotyledonous and Dicotyledonous. It is interesting to notice that the epochs which mark great changes in the terrestrial flora do not coincide with those which witnessed the great changes in the marine fauna.

The number of groups of animal and plant life which have become extinct during past geological times, and their proportions to those now living on the earth, are illustrated in Appendices B and C.

Summary of Palæontological History.—A review of the facts which have been ascertained concerning the appearance and disappearance of the forms of life during past geological periods leads us to the following conclusions.

1. The species of animals and plants die out or disappear, one by one, in consequence of the conditions for their existence becoming unfavourable, or from their failure to maintain a competition with other forms. Many examples of species that have certainly become extinct in historical times are known—such as the Great Auk, the Dodo, and Steller's Sea-cow. Great numbers of individuals may be destroyed by 'catastrophes,' such as earthquakes, volcanic eruptions, or floods, but no proof has ever been obtained of a species having thus become extinct.

2. The new forms of life which have been constantly coming into existence upon the earth during past geological times have appeared *one by one*. Great changes in the fauna and flora of a district can always be correlated with the lapse of long periods of time. When we have a *continuous* series of deposits, however, the new forms of life make their appearance 'as single spies, and not in whole battalions.'

3. The new forms of life that thus make their advent seem in all cases to be related—and generally very closely related—to forms that have preceded them. The supposed cases of the

sudden appearance of types without any precursors break down upon rigid examination of the evidence.

4. Animals or plants of more complex organisation die out and are replaced by new forms more rapidly than those of simpler structure—Vertebrates change more rapidly than Mollusca, and Mollusca more rapidly than Foraminifera.

5. During the later geological periods, 'life-provinces' were identical with those of the present day; but as we go backwards in time the limits of these provinces become less clearly defined; and in all the earlier periods of the earth's history (Mesozoic and Palæozoic), though there were life-provinces, these had no relation whatever to those of the existing flora and fauna.

6. As a general rule, the most highly specialised forms of life have made their appearance on the earth later than the less specialised. Many of the older forms are what naturalists call 'synthetic types,' and exhibit, in combination, characters now displayed only in different species, genera, families, or orders.

7. There are certain cases—like those of the horses (see p. 178), the camels, the elephants, and other highly specialised groups—in which ancestral forms have been discovered in sufficient numbers to enable us to trace out with tolerable accuracy the general line of their descent, and the successive modifications by which these remarkable types have assumed their peculiar characters.

8. On the other hand, there are undoubtedly many remarkable groups of animals and plants, both living and extinct, concerning which there is at present no palæontological evidence available which would enable us to trace their probable descent from pre-existing types. This, however, is no more than we might expect if we bear in mind the necessarily imperfect character of the geological record.

9. Hence it must be conceded that, with respect to a large proportion of the known forms of animal and plant life, it is impossible to construct 'genealogical trees' on the basis of palæontological evidence.

10. But in spite of the fact that the chance of finding ancestors *in the direct line of descent* for living species is often a remote one, yet the evidence afforded of the existence of forms *collaterally* related to them is sometimes of very great value if it be rightly interpreted.

11. Although types which serve to bridge over gaps in our series of existing life-forms seem sometimes to arise, without any forerunners that can be regarded as linking them with pre-existing groups, yet instances of this kind often disappear and

become more and more easily explicable as the result of further research and as new discoveries are made.

12. Much of the difficulty of tracing the descent of forms of life, from the study of palæontological evidence, arises from the imperfect preservation of fossil types, and the consequent impossibility of making complete comparisons with living types. Of the actual relations of the soft parts of the Graptolithida, Stromatoporida, Monticuliporida, &c., with those of living groups, the evidence is unfortunately altogether wanting.

Such being the facts of the palæontological history, it remains for the zoologist and botanist to find their explanation, and to say with what theory or theories of the origin of species that history is most consistent.

TABULAR VIEW

OF

THE FOSSILIFEROUS STRATA.

SHOWING THE ORDER OF SUPERPOSITION OR CHRONOLOGICAL SUCCESSION OF THE PRINCIPAL GROUPS, WITH REFERENCE TO THE PAGES WHERE THEY ARE DESCRIBED IN THIS WORK.

SYSTEMS	BRITISH DEPOSITS	FOREIGN DEPOSITS
PLEISTOCENE (POST-PLIOCENE)	Clyde marine strata, with canoes (p. 164) River gravels of the South of England (p. 161) Cavern deposits of Kent's Hole, Brixham, &c. (p. 160) Glacial drift of Scotland and the North of England (p. 165) Erratics of Chichester, &c. (p. 168) Glacial drifts with marine shells of Moel Tryfaen, &c. (p. 168) Glacial formations of East Anglia (p. 166)	Danish Kitchen-middens (p. 159) Lake-dwellings of Switzerland (p. 240) Dordogne caves—reindeer period (p. 239) Champlain period of North America (p. 245) Older valley gravels and brick-earths of Amiens (p. 161) Loess of Rhine (p. 162) Deposits in caverns of Liège, &c. (p. 159) Australian cave-breccias with bones of extinct marsupials (p. 241) Glacial drift of Northern Europe (p. 237) Glacial drift of the Alps (p. 238) " " North America (p. 245)

SYSTEMS	BRITISH DEPOSITS	FOREIGN DEPOSITS
NEWER TERTIARY (NEOGENE or NEOCENE) PLIOCENE	Forest-bed of Norfolk cliffs (p. 183) Chillesford sands and clays (p. 184) Norwich crag (p. 185) Red crag (p. 185) White crag (p. 187) Stone-bed at base of crags (p. 189) St. Erth beds (p. 190) Lenham beds (p. 189)	Marine beds at base of Etna (p. 233) Sicilian strata (p. 233) Lacustrine strata of the Val d'Arno (p. 234) German and French pliocene (pp. [227, 229) Diestien and Antwerp crags (p. 228) Subapennine marls and sands (p. [232) Pliocene of North America (p. 244) Beds of Pikermi, Greece (p. 236) Strata of Siváliks, India (p. 236)
MIOCENE	Wanting	Faluns of Touraine (p. 226) " " Bordeaux (p. 227) Swiss beds of Oeningen (p. 231) Marine molasse of Switzerland (p. 231) Congeria beds of Vienna basin (p. [235) Strata of Mayence basin (p. 229) Beds of Superga, Turin (p. 232) Marine Miocene of India, &c. (p. 236)
OLDER TERTIARY. (EOGENE) OLIGOCENE	Wanting Hempstead (Hamstead) beds (p. 203) Bembridge series (p. 204) Brockenhurst series (p. 207) Headon series (p. 206)	Upper Oligocene of Germany (p. 228) Calcaire de la Beauce (p. 223) Gypseous series of Montmartre (p. 222) Strata of the Limagne, Auvergne [(p. 223) Aquitanian and lower molasse of Switzerland (p. 230) Rupelian and Tongrian of Belgium (p. 225) Brown coal of the Lower Rhine [(p. 228) Septaria clays and marine beds of Egeln (p. 228) Deposits of Vienna basin (p. 235) Croatian brown coal (p. 234) Nari series of India (p. 236)
EOCENE	Barton sands and Barton clay (p. 207) Bracklesham beds (p. 208) Bournemouth beds (p. 210) Bagshot beds (p. 213) Bovey Tracey beds (p. 212) London clay (p. 214) Oldhaven beds (p. 216) Woolwich and Reading series (p. 217) Thanet sands (p. 218)	Marine gypseous series (p. 222) Calcaire de St. Ouen (p. 222) Grès de Beauchamp (p. 222) Wemmelian beds of Belgium (p. 222) Uinta group of North America [(p. 242) Calcaire grossier of France (p. 221) Laekenian and Bruxellian of Belgium (p. 222) Arctic leaf-beds (p. 201) Nummulitic limestone of Europe, Asia, and Africa (p. 229) Bridger group of North America (p. 242) Sables de Cuise (p. 221) Paniselian, Ypresian, Landenian, and Heersian beds of Belgium (p. 221) Argile plastique (p. 221) Zeuglodon beds of North America (p. 242) Wahsatch beds of North America (p. 242) Montian beds of Belgium and France (p. 220)

Systems	British Deposits	Foreign Deposits
CRETACEOUS	Wanting	Laramie beds of North America (p. 337) Maestricht and Faxoe beds (p. 327) Pisolitic limestone (Danian of France) (p. 327)
	Upper chalk (p. 254) Middle chalk (p. 261) Lower chalk with chalk marl and Upper Greensand (p. 262) Blackdown beds (p. 264)	Senonian of France (p. 249) Turonian of France (p. 249) Cenomanian of France (p. 249) White chalk of Sweden and Russia (p. 254)
	Gault (p. 264) Sands of Folkestone, Sandgate, and Hythe (p. 266) Atherfield clay (p. 267)	Sands of Aix-la-Chapelle (p. 326) Quader sandstein and Planer-Kalk of North Germany (p. 326) Hippurite limestone of South France (p. 330)
	Tealby series of Lincolnshire (p. 268) Speeton clay of Yorkshire (p. 268)	Sands and clays of New Jersey, U.S. (p. 334) Series of Western United States (p. 335)
	Punfield beds (p. 274)	Aptian, Urgonian, and Neocomian of Europe (p. 331)
	Wealden clays and Hastings sands (p. 271)	Wealden of Hanover (p. 326)
JURASSIC	Upper, middle, and lower Purbecks (p. 286) Portland stone and sand (p. 292)	Marls with *Exogyra virgula* of Argonne (p. 325) Lithographic slate of Solenhofen (p. 283)
	Kimeridge clay (p. 292) Coral rag and calcareous grit (p. 294)	Nerinean limestone of the Jura (p. 295)
	Oxford clay (p. 295) Kellaways rock (p. 296)	White Jura (p. 326)
	Great or Bath oolite (p. 296) Stonesfield slate (p. 299) Fuller's earth (p. 301) Inferior oolite and sand (p. 301)	Brown Jura (p. 326)
	Upper lias sands and clay (p. 304) Marlstone (p. 304) Middle lias clay (p. 305) Lower lias clays and limestone (p. 305)	Lias or black Jura (p. 326)
	Zone of *Avicula contorta* ('Penarth beds') (p. 308)	Rhætic (Kössen beds) (p. 308)
TRIAS	Keuper or Upper New Red sandstone, &c. (p. 317) Red shales of Cheshire and Lancashire, with rock-salt (p. 321) Dolomitic conglomerate of Bristol (p. 319)	Keuper beds of Germany, &c. (p. 324) St. Cassian and Hallstadt beds, with rich marine fauna (p. 328) Coalfields of Richmond (Virginia) and Chatham (N.C.) United States (p. 333)
	Wanting	Muschelkalk of Germany (p. 324)
	Bunter or Lower New Red sandstones of Lancashire, Cheshire, &c. (p. 320)	Bunter-Sandstein of Germany, &c. (p. 324)

SYSTEMS	BRITISH DEPOSITS	FOREIGN DEPOSITS
PERMIAN	Upper Permian of Cumberland (p. 343) Middle Permian, magnesian limestone, and marl slate of Durham and Yorkshire (p. 343) Lower Permian sandstones and breccias of Penrith, Dumfriesshire, &c. (p. 347)	Dark-coloured shales of Thuringia, &c. (p. 393) Zechstein or dolomitic limestone (p. 393) Mergelschiefer and Kupferschiefer (p. 393) Roth-todt-liegendes of Thuringia (p. 393) Magnesian limestones, &c., of Russia (p. 393) Sandstones of Artinsk (p. 393)
CARBONIFEROUS	Coal-measures of South Wales, &c. (p. 349) Coal-measures of Midlands and North of England (p. 367) Flat coals of Scotland (p. 368) Millstone grit (p. 368) Yoredale series of Yorkshire (p. 369) Tuedian coal-measures of Northumberland (p. 349) Carboniferous limestone and shale of England (p. 369) Carboniferous limestone and carboniferous slate of Ireland (p. 370) Edge coals of Scotland (p. 370) Calciferous sandstone series of Scotland (p. 370)	Coalfields of France, Belgium, and Germany (p. 392) Fusulina limestones (p. 393) Upper and lower Coal-measures of the United States (p. 394) Productus limestones of Russia (p. 393) Coal-measures of Russia (p. 393) Conglomerates, limestones, and shales of Appalachians (p. 394)
DEVONIAN and (OLD RED SANDSTONE)	Pilton group of North Devon (p. 386) Petherwyn beds of Cornwall (p. 386) Yellow sandstones of Dura Den (p. 389) Kiltorcan beds of Ireland (p. 390) Ilfracombe beds and limestones of Torquay and Plymouth (p. 386) Flagstones of Forfarshire (p. 389) Bituminous schists of Gamrie, Caithness, &c. (p. 389) Sandstones and slates of the Foreland and Lynton (p. 386) Sandstones and cornstones of Herefordshire (p. 390)	Clymenien-Kalk and Cypridinen-Schiefer of the Eifel (p. 391) Goniatite beds of the Eifel (p. 391) Limestones of Eifel with underlying Calceola schists (p. 392) Catskill, Chemung, and Portage beds of North America (p. 393) Devonian strata of Russia (p. 392) Hamilton, Helderberg, and Oriskany strata of North America (p. 393) Sandstones of Gaspé (p. 393)

Systems	British Deposits	Foreign Deposits
SILURIAN	Upper Ludlow formation, Tilestones, Downton sandstone and bone-beds (p. 405) Lower Ludlow formation, Aymestry limestone (p. 406) Wenlock limestone and shale (p. 407) Woolhope limestone and grits (p. 408) Tarannon shales and Denbighshire grit (p. 408) Upper Llandovery or May Hill sandstones (p. 409) Lower Llandovery beds (p. 409)	Gothland limestone of Scandinavia (p. 430) Onandaga salt group of North America (p. 430) Etage E of Bohemia (p. 429) Niagara Limestone of North America (p. 430) Pentamerus limestones and shales of Scandinavia and Russia (p. 430) Clinton and Medina sandstones of North America (p. 430)
ORDOVICIAN	Bala limestone and Caradoc beds (p. 415) Llandeilo beds (p. 417) Arenig or Stiper-stones group (Lower Llandeilo of Murchison) (p. 418)	Trinucleus shales and Cystidean limestone of Scandinavia (p. 430) Graptolitic shales of Scandinavia. Etage D (d_2, d_3, d_4, d_5) of Bohemia (p. 429) Orthoceras limestone of Scandinavia (p. 430) Hudson river, Cincinnati, Trenton, and Chazy beds of North America (p. 431)
CAMBRIAN	Durness and Girvan limestones of Scotland (p. 428) Tremadoc slates (p. 425) Lingula flags (p. 426) Menevian beds of Wales (p. 426) Harlech grits and Llanberis slates (p. 427) Comley sandstones and Olenellus beds of Scotland (p. 427)	Calciferous sandstones of North America (p. 430) Alum shales of Scandinavia (p. 430) 'Primordial' beds (Etage C) of Bohemia (p. 429) Potsdam sandstones of North America (p. 430) Olenellus beds of Scandinavia (p. 430) Olenellus slates of Georgia, &c., North America (p. 430)
	Pebidian beds of Wales (p. 434) Arvonian (?) beds of Wales (p. 434) Dimetian beds of Wales (p. 434) Uriconian beds of the Midland (p. 435) Longmyndian strata of the Midlands (p. 435) Torridonian strata of Scotland (p. 435) Lewisian strata of Scotland (p. 434)	Huronian strata of North America (p. 436) Keeweenawan strata of North America (p. 437) Animike, Keewaten, and Coutchiking beds of North America (p. 437) Gwalior, Dhwárwár, Bigawar, Aravalli, and Cuddapah beds of India (p. 438) Upper Laurentian and Lower Laurentian of North America (p. 437)

PART III

VOLCANIC ROCKS

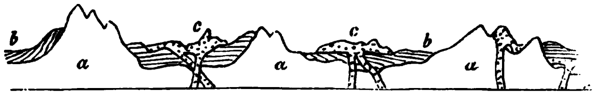
CHAPTER XXX

VOLCANIC ROCKS, THEIR NATURE AND COMPOSITION

Relation of volcanic Rocks to the sedimentary hypogene Rocks—Nature of Action taking place at Volcanic vents—Lavas and their Varieties—Fragmental materials ejected from Volcanoes—Scoriæ, lapilli, dust, pumice, bombs—Formation of volcanic Tuffs—Alteration of volcanic Rocks by solfataric and atmospheric agencies—Chemical composition of lavas—Acid, intermediate and basic lavas—Rhyolites and Soda-rhyolites—Andesites, Trachytes, Phonolites and Tephrites—Alteration of Andesites—Propylites and Porphyrites—Basalt and Melaphyres—Tachylytes and Variolites—Basaltic and Palagonite Tuffs.

Relations of Volcanic Rocks to those of other classes. The aqueous or fossiliferous rocks having now been described, we have next to examine those which may be called volcanic in the most extended sense of that term. Suppose *a a* in the

Fig. 632.



a. Hypogene formations, plutonic and metamorphic.
b. Aqueous formations. *c*. Volcanic rocks.

annexed diagram to represent the crystalline formations, such as the granitic and metamorphic; *b b* the fossiliferous strata; and *c c* the volcanic rocks. These last are sometimes found, as was explained in the first chapter, breaking through *a* and *b*, sometimes overlying both, and occasionally alternating with the strata *b b*.

Nature of Volcanoes and of Volcanic Action.—Volcanoes are apertures in the earth's crust, through which various materials, usually in a highly heated condition, find their way to the surface. The substances thrown out of volcanic vents are

sometimes in a gaseous condition, sometimes liquid, and at other times solid. The gases given off by volcanoes are chiefly water-gas or steam, sulphurous acid, hydrochloric acid, and (during the later stages of the history of a volcano) carbon dioxide; but many other substances, such as boric acid, hydrofluoric acid, ammonium chloride, and various metals and metallic sulphides, in a vaporised condition, also escape from volcanic orifices. The chief liquid thrown from volcanic vents is water, when the temperature is not so high as to convert it into steam. Many hot and mineral springs are clearly connected with volcanic activity within the earth's crust; and, as shown by the late Mr. Robert Mallet, 'geysers,' in all their essential characters, are identical with explosive volcanoes, though hot water instead of molten lava is thrown out from them. The water of geysers and hot springs often contains silica, calcium carbonate, and other materials in solution, and these substances are deposited around them.

In most of the ordinary volcanoes, however, various kinds of rock, either in a molten or a solid state, are ejected and accumulate round them to form conical volcanic mountains, the vent remaining as an aperture or cup-shaped hollow ('crater') at the summit or on the side of the volcanic cone.

Nature of Lavas.—When liquid, this 'lava' (as the molten rock is called) looks like a red- or white-hot slag, but it usually gives off great quantities of steam and other gases, water being evidently imprisoned in the midst of the molten mass, and escaping into the atmosphere when the pressure is relieved by the lava reaching the surface. Some lavas are so liquid that they

Fig. 633.

Ropy Surface' of lava stream.

flow like rivers over the surface of the earth; and such lavas generally exhibit remarkably rough and cindery surfaces, due to the escape of steam and gases from them as they flow along. Other lavas are remarkably viscous, sometimes moving along like glaciers at the rate of a few inches a day; lavas of this type usually exhibit a smooth surface, which is often wrinkled and twisted so as to resemble coils of rope, 'ropy surfaces' (see fig. 633 and fig. 653, p. 471).

Ejected Fragments.—The solid materials thrown from volcanic vents consist of blocks of lava, sometimes compact, but

more frequently distended by gas so as to resemble a cinder (*scoria*). When the scoriæ are small (about the size of a nut) they are called by the Italian name of *lapilli*, and when reduced to a granular or sandy condition they form 'puzzolana,' while when perfectly comminuted they are known as volcanic dust or volcanic ash.

Volcanic scoriæ are sometimes spoken of as 'cinders,' which in outward aspect they greatly resemble. Fine volcanic dust in the same way is often called 'ash;' but it must be remembered that these terms only indicate the *general appearance*, and not the *origin* of the substances. There is no real analogy between the pieces of half-burnt coal known as 'cinders' and the masses of mixed silicates, which have been distended by gases while they were in a fused condition, that we call scoriæ; equally little is there in common between the 'ash,' or incombustible residue left by the burning of coal, &c., and the fine dust produced by the trituration of scoriæ and pumice. Volcanic scoria and dust are so like cinders and ash in outward appearance, that it is almost impossible to avoid using these names for them; it must always be remembered, however, that volcanic materials are not, like cinder and ash, products of *combustion*. There is, indeed, little or no *burning* taking place at a volcanic vent, nor does the action of a volcano depend on combustion. The red glow above a volcanic vent is due to reflection from the clouds of steam and dust above the crater, of the surfaces of glowing lava within it. The loud rumbling sounds, the trembling of the ground, the intense darkness, the lightning flashes, and the heavy falls of rain which accompany and follow violent volcanic eruptions are all consequences of the escape of great masses of watery vapour from the midst of masses of molten rock in which it has been occluded, and the ejection of fragments of lava by the agency of this escaping steam. A few inflammable gases, it is true, escape and take fire on reaching the outer air, but these are not highly luminous, and 'flames' are never conspicuous in a volcanic outburst.

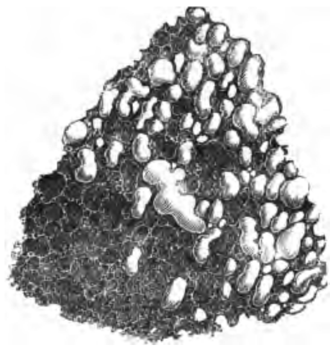
Round or fusiform masses of lava, partially distended by gas, which have assumed a more or less regular form by rotation during their flight through the atmosphere, are known as *volcanic bombs*. These must not, however, be confounded with the fragments of scoria coated with lava, over which they have rolled, these being known to geologists as *pseudo-bombs*.

When a lava is glassy and becomes distended by gas, it forms the well-known material called 'pumice.' Sometimes the volcanic glass is drawn out into delicate threads like the 'Pelé's hair' of Hawaii, or it may give rise to the beautiful material

described by the late Professor Dana as occurring in the same district and known as 'thread-lace scoria.'

Scoriæ which have been buried in the earth's crust often have their cavities or steam-holes filled with various minerals, these having been formed by the solvent action of water permeating the substance of the lava. Such rocks are said to exhibit an *amygdaloidal* structure, from the Greek word *amygdalon*, an almond (see fig. 634). Rocks of this kind, indeed, sometimes very closely resemble the well-known sweetmeat known as 'almond-hardbake.' The substances which fill up the cavities in these amygdaloidal rocks are usually opal, quartz, calcite, or the various crystallised hydrous silicates known as 'Zeolites.'

Fig. 634.



Scoriaceous lava in part converted into an amygdaloid by infilling of its cavities. Montagne de la Veille, Department of Puy-de-Dôme, France.

Besides lava in various forms, volcanoes frequently discharge fragments of rock torn from the sides of their vents, often at great depth from the surface. Such ejected blocks may be of aqueous origin and contain fossils; but they are often much altered and sometimes have become completely crystalline in consequence of their contact with the masses of molten lava.

Volcanic Tuffs.—The loose materials ejected from volcanoes often become cemented to form a more or less hard and solid stone. Of this class is the 'peperino' of the Italian geologists, a light spongy rock often used as a building material, and made up of lapilli cohering to form a rock suitable for building purposes. Scoriæ, lapilli, puzzolana, pumice, and volcanic dust, when acted upon by atmospheric waters containing carbon dioxide, undergo chemical changes, the calcium silicate being converted into carbonate which acts as a cement to the whole mass, while in other cases secondary silicates are formed, which play the same part. The general name applied to rocks formed of coherent fragmental volcanic material is 'volcanic tufa' or 'tuff,' which must of course be clearly distinguished from the calcareous tufa deposited by mineral springs. The 'trass' of the Eifel district is a rock composed of lapilli and dust which when quarried and exposed to the air sets to form a very solid

and useful building-stone. The fine dust of volcanoes, when mixed with water, often sets in the same way into a hard mud. The various tuffs and volcanic muds not unfrequently contain remains of plants and land-shells; when deposited in the sea, they may enclose shells and other marine organisms.

Lavas and fragmental materials about dormant and extinct volcanoes (solfataras) are often found greatly affected by such volcanic emanations as sulphurous acid, hydrochloric acid, carbon dioxide, &c., and in consequence of this *solfataric action* many of the minerals of which volcanic rocks are composed are found to be much altered or even converted into 'pseudomorphs,' while new substances such as quartz, chalcedony, opal, &c., are found filling their cavities and fissures.

Chemical Composition of Lavas.—Lavas when analysed are found to consist of mixtures of various silicates—among the chief of which are the silicates of aluminium, calcium, magnesium, iron, sodium, and potassium; but water and other compounds of hydrogen are almost invariably present also. In some cases, the proportion of silica in lavas is very high, from 66 to 80 per cent.—and the rock is said to be an *acid lava*. In other cases the proportion of silica is low—55 to 40 per cent.—and such a lava, in which the bases preponderate over the acid silica, is called a *basic lava*. Lavas in which the proportion of silica varies from about 55 to 66 are called by English geologists *intermediate lavas* ('*laves neutres*' of French authors).

Structure of Lavas.—Lavas differ from one another greatly in structure or texture. Some lavas are almost destitute of crystalline matter and form glassy, vitreous, or hyaline masses. At other times the lava-rocks, while perfectly compact, display, instead of the 'vitreous lustre' of glass, the 'resinous lustre' of pitch; such rocks are known as 'pitchstones.' Many other lavas exhibit a finely granular or stony appearance. Lavas often contain included crystals of felspar or some other mineral scattered through them ('phenocrysts' of American geologists), and such rocks are said to have a *porphyritic* structure. Glassy and stony lavas may alike exhibit this porphyritic structure. The original porphyry of the ancients (*porfido rosso antico*) is an old andesitic lava in which the base or ground-mass has acquired by alteration a rich purple tint, while white felspar crystals are seen scattered through it (see fig. 635). The term 'porphyritic' is now, however, applied to any rock containing large scattered crystals, without reference to its colour.

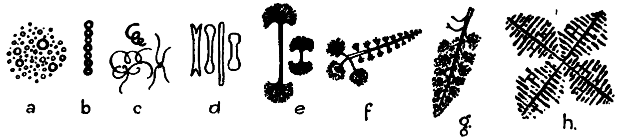
Fig. 635.

Porphyry.
White crystals (phenocrysts) of felspar in a dark purplish base.

When the base or ground-mass of a lava is studied in thin sections

under the microscope, we find more or less glassy matter through which are scattered embryo and minute crystals ('crystallites' and 'microlites'). Sometimes these microlites are found grouping themselves to form skeleton crystals, the spaces around being left more or less clear, and forming 'courts of crystallisation;' at other times the

Fig. 636.



Crystallites, microlites, and skeleton crystals in glassy rocks.
a. Globulites, *b.* margarites, *c.* trichites, *d.* belonites, *e. f. g.* fern-like aggregates of microlites from the pitchstone of Corriegills, Arran, *h.* skeleton crystal of magnetite from a tachylyte or basalt-glass.

microlites group themselves into spherical aggregates (simple or compound), usually minute but occasionally several inches or even feet in diameter which, are called 'spherulites' (see fig. 638). When empty cavities, probably formed by contraction during crystallisation, exist in these spherulites, they are known as 'lithophyses' (hollow spherulites). The disposition of the porphyritic crystals, the microlites and the crystallites, in a lava often indicates, by their parallel arrangement, that the molten mass has been in motion after the development of these structures within it. The rock is then said to exhibit a fluidal or banded structure (see fig. 637). Movement is also indicated by the drawing out of gas-bubbles, which exist in

Fig. 637.

Glassy rock exhibiting banded or fluidal, and perlitic structure.

Fig. 638.

Glassy rock, partially devitrified, and showing spherulitic structure.

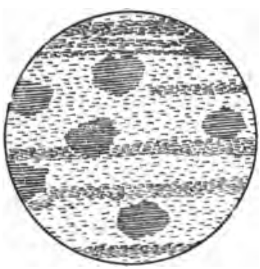
almost all lavas, and have been formed by escaping steam; such lavas, when glassy, are said to be 'pumiceous' in structure; they sometimes exhibit a beautifully satiny sheen ('Schiller'), due to the presence of these drawn-out cavities. Some glassy lavas are traversed by numerous fine cracks, straight and curved, and in consequence of these they often produce interference colours and sometimes break up into small round particles. Such lavas are said to

have a 'perlitic' structure, and they are then spoken of as perlites (see fig. 637). The 'axiolitic' structure of Zirkel appears to arise when spherulites tend to form along the sides of perlitic and other cracks in glassy rocks.

When minute 'lath-shaped' microlites of felspar are entangled in a mass of glass the ground-mass of the lava is said to be a 'microlitic felt' (see figs. 641, 642); when somewhat larger crystals of felspar are enclosed in augite or some other mineral, the lava is said to have an 'ophitic' (diabasic) structure (see fig. 688, p. 518); the fracture along cleavage-planes of a mineral enclosing others in this way gives rise to the appearance known as 'lustre mottling' in rocks.

Acid Lavas, Rhyolites, &c.—The lavas of acid composition are now generally spoken of by geologists as Rhyolites; occasionally, however, the terms Liparites and Quartz-trachytes are applied to them. Forms of these lavas which have undergone partial recrystallisation (secondary devitrification, resulting from hydration, kaolinisation, and other chemical changes) are spoken of as 'quartz-felsites,

Fig. 639.



Obsidian from Iceland, showing flow structure in the parallel arrangement of the microlites and incipient spherulites formed of aggregates of crystallites.

Fig. 640.

Rhyolite from Hungary, with a devitrified spherulitic base. The clear rounded crystals are quartz, containing glass and stone cavities. The rectangular crystals are felspar (orthoclase).

'porcellanites,' 'halleflintas,' 'pyromerides,' 'porphyroides,' &c. The rhyolites are usually pale in colour (white, grey, or pink), and they have a low specific gravity (varying from 2·6 in the stony varieties to 2·3 in the glassy forms). They much more usually exhibit glassy varieties than do any other classes of lavas. When crystallised they always contain quartz, in distinct crystals or in corroded and rounded grains, with porphyritic crystals of orthoclase; more rarely plagioclase, biotite, hornblende, or augite; magnetite and apatite also occur, and, as accessories, garnet, cordierite, zircon and other minerals. Olivine, however, is very rarely, if ever, found in the rhyolites.

The most stony rhyolites, or those in which the glass is not conspicuous, are known as 'lithoidites' by the American petrographers (see fig. 640). A form in which the porphyritic crystals are so large and numerous that the rock resembles at first sight a granite, is called 'Nevadite.' Many of the stony rhyolites exhibit beautifully porphyritic and spherulitic structures. When the rock is fine-grained and com-

pact it is often called 'hornstone.' Varieties exhibiting the lustre of pitch or resin are known as pitchstone ('retinite' of French authors), while those in which the ground-mass is perfectly vitreous or glassy are called Obsidian (see fig. 639). Pitchstones and Obsidians exhibit the banded, fluidal, spherulitic, perlitic and pumiceous structures in great perfection. There is often a complete passage from the most stony or highly crystalline forms of rhyolite, through compact and resinous types to the glassy obsidian, and its frothy form pumice. Fragments of these materials accumulate to form rhyolite- and pumice-tuffs, which often contain opal and tridymite.

Most rhyolites contain a large proportion of potash as compared with soda, but in some cases the proportion of soda is higher than the potash. Such lavas are called soda-rhyolites or 'quartz-pantellerites, from their occurrence in the Island of Pantelleria. They often contain, in addition to the quartz-crystals, 'phenocrysts' of a soda-orthoclase (anorthoclase) or soda-microcline, and of a soda-hornblende (Ænigmatite or Cossyrite).

As the rhyolites more readily assume the glassy condition than any other class of lavas—owing to the large proportion of alkalies which they contain—the special characteristics of glassy rocks are peculiarly well exhibited by them. It is among the rhyolites that we find the most striking examples of spherulitic and perlitic structure, while it is the same class of rocks that furnish the finest and most perfect varieties of 'pumice.'

When the alumino-alkaline silicates of the rhyolites are acted upon by sulphurous acid, various hydrous sulphates are formed ('alunite,' &c.), and the altered rock is known as 'alumstone;' this rock, when roasted and washed, yields crystals of alum. In Hungary and other districts, extensive deposits of alumstone are found which have evidently been produced by solfataric action on ordinary rhyolites. By the action of atmospheric agents (carbon dioxide and water) on rhyolites, various stages of alteration and decomposition are brought about, and different names have been applied to these altered forms. In this country many of the altered rhyolite lavas are known as felsites and quartz-felsites; rocks of this class with a spherulitic structure are called by the French geologists 'pyromerides;' when incipient foliation has been produced in them they have been called 'porphyroides,' and when this action has gone further they may be converted into 'quartz-schists.'

Intermediate Lavas.—The lavas of intermediate composition contain from 55 to 66 per cent. of silica; they have as a rule a darker colour than the rhyolites and a density varying from 2·8 in the stony varieties to 2·5 in the glassy forms. They more rarely assume this glassy form, however, than do the rhyolites; but many forms of pitchstone and obsidian, with spherulitic and perlitic varieties, and some pumices, are of intermediate composition. The lavas of intermediate composition usually contain quartz only as an accessory constituent, while olivine, though occasionally present in them, cannot be regarded as one of their essential minerals.

Andesites.—By far the largest and most important group of the intermediate lavas is that known as the 'Andesites.' They are rocks composed essentially of crystals of plagioclase (soda-lime-felspar), with a pyroxene (augite or enstatite), hornblende or biotite and more or less glassy base. Usually the ground-mass of the rock exhibits the

aggregation of felspar microlites in a glassy base known as a 'microlitic felt,' so that this structure is often spoken of as being typically andesitic.

The Andesites fall naturally into two great groups, the hornblende- and biotite-andesites (see fig. 642), which incline towards the acid lavas, and the pyroxene-andesites (augite- and enstatite-andesites) inclining towards the basic lavas (see fig. 641). There are, however, curious links between these types—rocks which contain at the same time biotite and enstatite, or hornblende and augite. Some andesites contain a very high percentage of silica, and when this crystallises out as quartz the rock is known as quartz-andesite or 'dacite.' These

Fig. 641.

Augite-andesite, from Hungary. The white corroded crystals are felspar (plagioclase). In the upper part is seen a crystal of augite with its characteristic cleavage. The ground mass is a microlitic felt, and the rock contains much magnetite.

Fig. 642.

Hornblende-mica andesite from Hungary. The colourless zoned crystals are felspar (plagioclase). In the upper part are seen two crystals of hornblende with characteristic cleavage. In the centre is a crystal of mica (biotite). The ground-mass is a microlitic felt.

rocks may be regarded as belonging to the acid rather than the intermediate series. On the other hand, some of the augite- and enstatite-andesites are very dark-coloured, heavy rocks, and only differ from the basalts in not containng olivine.

Besides the large and widely distributed group of the andesites. the intermediate class of lavas contains several other groups of rock of considerable interest.

Trachytes.—The name trachyte was originally given to all light-coloured lavas in opposition to the black basalts; the term is now applied by petrographers to rocks consisting of crystals of orthoclase felspar (Sanidine) with subordinate plagioclase and hornblende, or augite set in a more or less glassy base (see fig. 643). Trachytes often contain as accessory constituents sodalite, melilite, olivine, and other minerals. The trachytes are far less common than the andesites, but are found not unfrequently not only among the products of recent volcanoes, but among those of earlier periods of the earth's history.

Phonolites and Tephrites.—When a rock of the trachytic type contains considerable quantities of the felspathoids, nepheline, leucite, hauyn, or nosean, it is called a *phonolite* ('clinkstone' of the old authors). The phonolites, though abundant in certain districts, like Bohemia and Central France, are not very widely distributed. In

this country, we find a good example of a phonolite only in the Wolf's Rock off the Land's End in Cornwall (see fig. 644), while some of the trachytes of Haddingtonshire contain small quantities of nepheline and approximate to phonolites in their structure and mineral constitution.

Rocks of andesitic type, that is, with a plagioclastic felspar predominating, which contain the felspathoids, nepheline, leucite, hauyn, &c., are known as *tephrites*. They form a class which is even less widely distributed than the phonolites.

Fig. 643.

Trachyte from Ischia. The large colourless crystals are orthoclase (sanidine); the dark crystals are hornblende. The base is formed of microlites of felspar with glass.

Fig. 644.

Phonolite from the Wolf's Rock, Cornwall. The long cracked crystals are sanidine, the clear square and hexagonal ones nepheline, and the dark-zoned ones nosean.

Lavas of intermediate composition undergo changes much more easily than the acid lavas, owing to their smaller proportion of silica and their higher percentage of iron oxides. Andesites which have been altered by solfataric action are called *propylites*; among trachytes which have been similarly altered we find the *domites* of Central France. When altered by the various atmospheric agents, the andesites are converted into the rocks known as *porphyrites*, though some of the rocks called by this name are plutonic rather than volcanic rocks. The phonolites, owing to the instability of their felspathoid constituents, are especially liable to alteration and disintegration.

Basic Lavas.—The lavas of basic composition contain less than 55 per cent. of silica; they are always dark and frequently even black in colour, and have a density varying from 2·9 in the stony varieties to 2·7 in their glassy forms. When quartz is present in these lavas, which is a rare occurrence, there is reason to believe that it has been caught up in the flowing mass, and is not an original constituent of the rock. The felspars present are lime-soda varieties (labradorite and anorthite); the ferro-magnesian silicate is usually augite; a considerable amount of magnetite or titanoferrite generally occurs in them. In addition to the minerals already mentioned, we nearly always find some olivine present in the basic lavas; and this mineral not unfrequently forms conspicuous granules, or even nodules of considerable size. Some authors, indeed, regard olivine as an essential constituent of the basic lavas.

Basalts, &c.—The general name applied to these basic lavas is *basalt*, the term *dolerite* being reserved for the coarser-grained varieties, which, as we shall see hereafter, occur more frequently as plutonic rocks. It was shown by Cordier that, in spite of its compact appearance, when viewed by the naked eye, ordinary basalt is really an aggregate of minerals—felspar, augite, olivine, and magnetite. By grinding the rock to powder and carefully lævigating it, Cordier was able to separate the several minerals according to their different densities; the same result can be much more easily attained at the present day by putting powdered basalt into liquids of different specific gravity; in a still more simple manner, we may examine not only the several minerals in the rock, but also their relations to one another, by making thin transparent sections of basalt and studying them under the microscope (see fig. 645). All the basalts contain more or less of a glassy material between their crystals; and basalts with an exceptional quantity of such glassy material are called magma-basalts.

Basalts sometimes contain, in addition to their essential minerals, enstatite, hornblende, or biotite. Locally distributed, we find basalts containing one or other of the felspathoids—leucite, nepheline, hauyn, or melilite—and these are known as leucite-basalts, nepheline-basalts,

Fig. 645.

Basalt, Isle of Mull. The lath-shaped crystals are felspar (plagioclase), the granular ones augite, the black opaque grains magnetite, and the large crystals in high relief olivine.

Fig. 646.

Leucitite from near Rome. The large polygonal crystals with symmetrical inclusions are leucite. Augite, biotite, and magnetite are also present with a glassy base.

hauyn-basalts, and melilite-basalts. Basalt-like rocks with leucite and nepheline, but without olivine, are called by continental authors leucitite (see fig. 646) and nephelinite.

The basalts show much less tendency to pass into a glassy state than do rocks of more acid composition. Occasionally, however, as in the surfaces of lava-streams and the margins of dykes, where rapid cooling has taken place, we find *basalt-glass* or *tachylyte* formed. This tachylyte may exhibit the banded, spherulitic, and perlitic structures so characteristic of vitreous rocks. Pelé's hair and the thread-lace scoria of Hawaii are beautiful pumiceous forms of a basalt-glass.

Owing to their smaller proportion of silica and the amount of

iron-oxides which they contain, the basaltic lavas undergo easy decomposition, often losing their black colour and assuming reddish and brownish tints. *Melaphyres* are forms of these altered lavas. When the basalt was scoriaceous, the cavities become filled up with various secondary minerals—calcite, quartz, zeolites, chlorites, &c.—and an amygdaloidal rock is produced (see fig. 634, p. 458). When a basalt-glass with spherulitic structure undergoes alteration, a rock is produced, which, from its fancied resemblance to the skin of a small-pox patient, has long been known as variolite.

The fragmental materials derived from the basaltic lavas are known as basalt-tuffs; the variety known as palagonite-tuff, which is common in Sicily and Iceland, contains the hydrous glass of secondary origin called by mineralogists 'palagonite.'

There are a very few lavas in which the proportion of silica is so low that they must be classified with the ultra-basic rocks, but these are of rare and exceptional occurrence.

Fuller details concerning the nature and structure of lavas will be found in the treatises on petrography by Dr. Hatch, Mr. Harker, and Mr. Rutley already referred to, in the 'British Petrography' of Mr. Teall, and in the treatises on the microscopic characters of rocks by Fouqué and Michel Levy, Zirkel and Rosenbusch.

CHAPTER XXXI

ORIGIN AND STRUCTURE OF VOLCANIC ROCK-MASSES

Explosive and effusive action of Volcanoes—Origin of Volcanic Cones—Internal structure of Volcanic Cones—Origin of Volcanic Craters—Formation of Volcanic Dykes—Varieties of Volcanic Dykes—Alteration of Rocks on the sides of Volcanic Dykes—Contact Metamorphism—Alteration of Sandstone, Shale, Limestone, and Coal—Interbedded and contemporaneous Volcanic Rocks contrasted with intrusive or subsequent masses—Columnar and globular structures in Lavas.

Different Kinds of Volcanic Action.—Volcanic activity is of a twofold nature—explosive and effusive. Sometimes great volumes of steam escape from the vent with terrible violence, carrying up considerable rock-masses, with bombs, scoriæ, lapilli, and dust, to the height of many miles into the atmosphere—and in such quantities as to completely darken the whole district around for hours, days, or even weeks. The larger fragments, when they fall back to the vent, are re-ejected, and this takes place again and again, till all are gradually reduced to an impalpable powder. This volcanic dust mingling with the rain, produced by the condensation of steam, sometimes flows down in rivers of mud, which consolidate to form beds of volcanic tuff. At each explosion of steam from the midst of the molten rock in a volcanic vent, a fresh surface of the glowing lava is exposed, and it is the ruddy

reflection of this upon the clouds of vapour and dust which is so frequently mistaken—especially at night—for flames, and has led to volcanoes being termed incorrectly 'burning mountains.' The friction between the ascending column of vapour, the ejected fragments, and the sides of the vent gives rise to the generation of electricity and the wonderful displays of lightning so common during volcanic outbursts. At other times, lava issues quietly from a volcano, with but comparatively little escape of steam; and the mass of molten rock flows as 'lava streams,' which are often of enormous volume. This *effusive* action may, like the *explosive* action, go on continuously for long periods—for days, weeks, months, or even years.

In many volcanoes, there occur alternations of explosive and effusive action. At the beginning of each eruption steam at high tension escapes from the vent, and explosions, following one another in rapid succession, discharge into the atmosphere vast quantities of fragmental materials. As the violence of the paroxysm gradually dies out, however, the explosive is succeeded by effusive action, and streams of lava flow out in the place of the violent discharges of scoriæ and dust.

But in some volcanoes the action is almost always explosive; thus the great volcanoes of Java appear to be wholly built up of loose materials projected from their vents, there being few if any examples of lava-streams. In other volcanoes, like those of the Hawaiian Islands, the action appears to have been almost entirely effusive; and the volcanic cones are built up of thick sheets of lava, piled one on the top of another, with hardly any layers of scoriæ or dust between them.

A striking example of effusive volcanic action on the grandest scale was afforded to geologists in 1783, when, at Skaptár Jokul, in Iceland, a great fissure opened, on which only some small scoria-cones were thrown up, but the two streams of lava issuing from this vent were in bulk equal to the mass of Mont Blanc! A century later, in 1883, the most violent explosive eruption on record occurred at Krakatoa in the Sunda Straits. There was no outflow of lava, but pumice and dust were thrown to the height of sixteen miles into the air, the pulsations of the atmosphere travelled two and a half times round the globe, violent waves were produced in the ocean, which were registered on the tide-gauges all over the world, and ejected materials were scattered over a circle with a radius of 1,000 miles!

External form, structure, and origin of volcanic Mountains.—In the case of Monte Nuovo in Southern Italy (see fig. 647), we have a volcanic cone, more than four hundred feet in height, with a large and deep crater at its summit, which was

formed by a series of explosive outbursts, lasting for three days, n the year 1538. The origin of the great volcanic cones with crater-shaped summits has been explained in the 'Principles of Geology' (chaps. xxiii. to xxvii.), where Vesuvius (see fig. 648),

Fig. 647.

Monte Nuovo, near Naples.

Fig. 648.

Vesuvius, with the old encircling crater of Monte Somma.

Fig. 649.

Barren Island in the Bay of Bengal, with an active cone rising in the midst of a large ancient crater.

Etna, Santorin, and Barren Island (see fig. 649), are described. The more ancient portions of those mountains or islands, formed long before the historic period, exhibit the same external features and internal structure as those of the extinct volcanoes of still higher antiquity. All these volcanoes were produced by the

same agencies which cause modern volcanic eruptions, and their materials belong to the same groups of rocks and only differ slightly in physical characters and in chemical constitution.

Ancient and Modern Cones and Craters.—In regions where the eruption of volcanic matter took place in the open air, and where the surface has never since been subjected to great

Fig. 650.

Group of volcanic cones in Auvergne, with their sides breached by the outflow of lava-streams.

aqueous denudation, cones and craters abound. Many hundreds of such cones still remain in Central France, in the ancient provinces of the Auvergne, Velay, and the Vivarais, where they form chains of hills. Although probably none of the eruptions have happened within the historical era, the ancient streams of lava may still be distinctly traced, descending from many of the craters, and following the lowest levels of the existing valleys (see fig. 650).

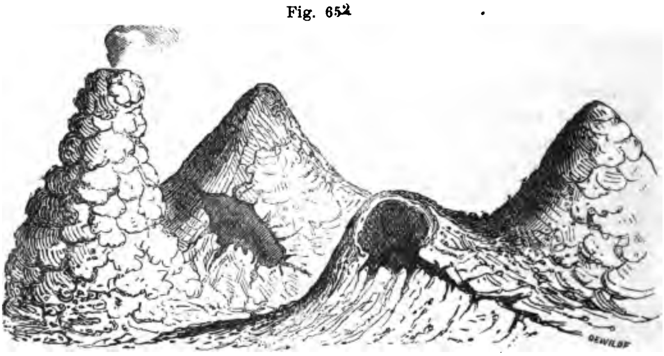
Fig. 651.

Ideal section of a scoria- or tuff-cone, showing the arrangement of the materials of which it is built up.

The origin of the cone and crater of the modern volcano is now well understood, the growth of many having been watched during volcanic eruptions. A chasm or fissure first opens in the earth, from which great volumes of steam are evolved. The explosions are so violent as to splinter the rocks in which the volcanic vent is opened, and hurl up into the air fragments of

broken stone, parts of which are shivered into minute portions. This stone is, in part, the rock which is penetrated by the uprushing steam, gases, and hot water, but mainly the volcanic rock which had been gradually forced up in a molten state. The showering down of the various ejected materials around the orifice of eruption gives rise to a conical mound, in which the successive envelopes of ash and scoriæ form layers, dipping on all sides from a central axis (see fig. 651). In the meantime a hollow, called a *crater*, has been kept open in the middle of the mound by the continued passage upwards of steam and other gaseous fluids. After a while, molten rock, quite liquefied (*lava*), usually ascends through the vent by which the gases make their escape. Although extremely heavy, this lava is forced up by the expansive power of entangled gaseous

Fig. 652



Small scoria-cones thrown up on the surface of lava-streams, Vesuvius. (After Schmidt.)

fluids and steam. Quantities of the lava are also shot up into the air, and burst into minute fragments called ash. Blocks of solid lava are ejected also, being more or less scoriaceous. The lava sometimes flows over the edge of the crater, and thus thickens and strengthens the sides of the cone; but sometimes it breaks down the cone on one side (see fig. 650), and often it flows out from a fissure at the base of the hill, or at some distance from its base. The lava in cooling assumes a clinkery or scoriaceous appearance.

Small cones made up of scoriæ thrown out in a pasty condition may accumulate into steep-sided, bottle-shaped, or chimney-like, piles (see fig. 652); ordinary 'cinder' or scoria cones have a slope of about 35°; 'tuff cones' are formed of lapilli, puzzolana or dust, which, when mingled with water, flow freely

and accumulate to form hills with a slope of about 17°. Lava-cones vary in form according to the liquidity or viscosity of the material; we have steep sides, massive 'mamelons,' like the phonolite-volcanoes of Bohemia (see figs. 653–654, 663), or the domitic 'puys' of Auvergne on the one hand; or greatly flattened domes with a slope of only a few degrees, as in the Hawaiian volcanoes on the other hand.

Fig. 653.

'Mamelon' composed of a ropy lava, Isle of Bourbon. (After Bory de St. Vincent.)

Fig. 654.

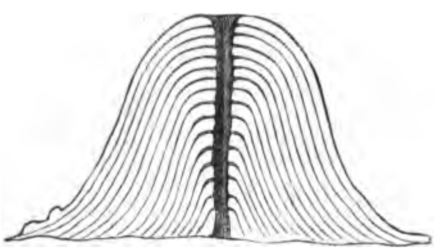
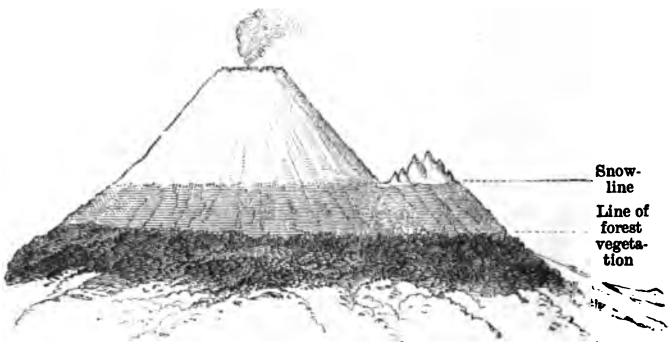


Diagram showing the probable internal structure of a lava-cone like fig. 653.

Internal Structure of Volcanic Cones.—The mode of origin of volcanic cones, as above described, is admirably exhibited when such cones have been partially swept away by the action of the waves of the sea or of rivers. We then find that the Scoria- or 'Cinder'-cones, like those of Auvergne, are composed of materials often exhibiting a most perfect stratification; the thin layers of which the cones are made up slope outwards and inwards, as shown in the diagram (fig. 651, p. 469). The degree of slope of the materials varies with their nature, rough cindery masses lying in steeper slopes than the finely comminuted matter, which, mingled with water, often flows as mud to consolidate as tuffs. Lava-cones are formed by the successive

outwelling of the liquid materials (see fig. 654). If this be viscous we get steep-sided domes like those of Bourbon, Bohemia, &c.; if the lava be very liquid, exceedingly depressed or flat domes are produced like the volcanoes of Hawaii, which have a slope of only 4°. The majority of volcanic cones are made up of alternations of lava and fragmental materials, and these are known as compound cones. By continual ejections from a vent, volcanoes may gradually grow up into conical mountains many thousands of feet high, like Cotopaxi (fig. 655). The volcanoes of Hawaii rise to a height of 30,000 feet from the ocean floor on which they stand. When 'lateral' or 'parasitical' eruptions occur on the sides of a volcano, it may lose its regular conical form and assume characters like those exhibited by Etna, the flanks of which are covered by parasitical cones.

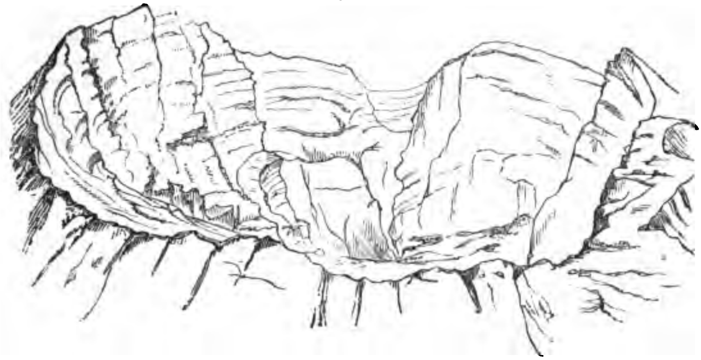
Fig. 655.



Cotopaxi (19,600 ft.), the highest active volcano in the world, seen from a distance of 90 miles. (After Humboldt.)

Origin of Volcanic Craters.—There is no doubt that the craters of volcanic cones are formed by violently explosive or paroxysmal outbursts. In fig. 656 we give a copy of Mr. Scrope's drawing of the crater formed at the summit of Vesuvius by the great eruption of 1822; it was more than 1,000 feet in diameter, and at least 1,000 feet deep. At an earlier date, as shown by the drawings of Sir William Hamilton, the cone rose to a much greater height, and within the crater small cones were formed, by gentle and long-continued eruption (see fig. 657). Since the great paroxysm of 1822 the vast crater has been filled up and the cone re-formed, though constant changes have taken place in the size and form of the summit-crater, and in the number of small cones within it. The tendency of the violent eruptions is to produce large craters truncating the summit of a volcano; but gentle and long-continued eruptions build up a cone within the crater, the sides of which may in the end become confluent with those of the great mountain itself, the height of which thus becomes greatly increased. This arrangement of cone within crater is very characteristic of volcanic mountains. Sometimes craters are formed of enormous dimensions; when com-

Fig. 656.

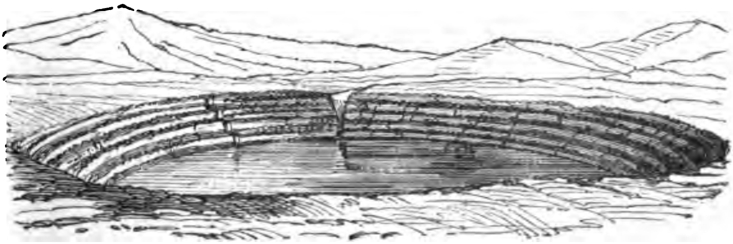


Great crater formed at Vesuvius during the eruption of 1822, 1,000 ft. in diameter and 1,000 ft. deep. (From a drawing by Scrope.)

Fig. 657.

Summit of Vesuvius in 1767. (After Sir William Hamilton.)

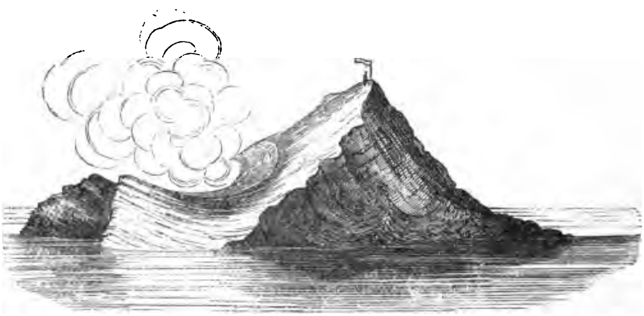
Fig. 658.



Crater-lake of Gustavila, Mexico. (After Humboldt.)

posed of tuffs or other materials impermeable to water they give rise to circular crater-lakes like fig. 658. There are crater-lakes in Italy, (Bracciano and Bolsena), which are respectively ten and twelve miles in diameter. It was held by Von Buch and Elie de Beaumont that craters were formed in volcanoes owing to the mountain being pushed up like bubbles and bursting at the top. But this 'theory of elevation-craters,' as it was called, has now been completely abandoned by geologists. At the same time it must be remembered that

Fig. 659.



Graham's Isle, a submarine volcano thrown up in the Mediterranean in 1831.

in some craters, like that of Kilauea in Hawaii, the lake of lava at the bottom may undermine the sides, and thus tend to enlarge the area of the crater.

Volcanoes are occasionally submarine, like the volcano thrown up in the Mediterranean and known as Graham's Island (see fig. 659),

Fig. 660.

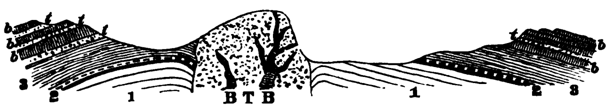
Part of the chain of extinct volcanoes called the Monts Dôme, Auvergne. (Scrope.)

and build their way up to the surface, being exposed to the action of waves and tides. Some volcanic eruptions, both at the present day and in the remote past, took place along lines of fracture of the earth's crust, and lava welled out, and sheets and flows were produced on a grand scale with the formation of only small cones. Ancient volcanoes were as large as the modern, and as active. They show by their linear arrangement that they were formed on lines of fissure (see fig. 660), and followed the law of occurring on areas which are undergoing elevation. Denudation has, in many instances, worn the

old volcanoes nearly to the surface of the earth, yet some of the remains of the central vent and of the sloping layers around it enable the original dimensions to be estimated. All through the earth's history, internal heat, and the presence of water in deeply seated rocks, have given rise to volcanic action.

Volcanic matter, in the form of lava, bursts forth under certain circumstances through the body of the volcanic cone, or if it does not reach the outside, it solidifies within, and is called a dyke.

Fig. 661.



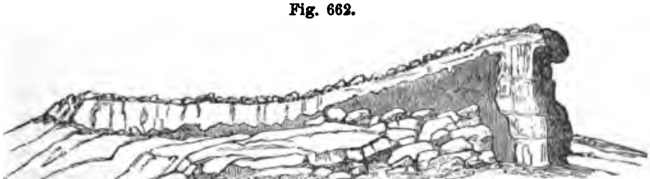
Section across the Binn of Burntisland, Fife. (After Geikie.)
1. Sandstones; 2. Limestone; 3. Shales. *b b.* Interbedded basalts; *t t.* Bedded tuffs. Tuff filling the old volcanic orifice of the Binn; B. Basalt dykes.

Similar outbursts occurring beneath the surface of the earth cause masses of volcanic rock to be injected through and between the sedimentary strata.

By denudation we have exposed to our view great masses of material which have formed the centres and lower portions of volcanic cones. Such rudiments of volcanoes were called by Darwin the 'basal wrecks' of volcanoes. Among the lava-masses injected into volcanic cones and the strata underlying and surrounding them, we recognise dykes, intrusive sheets (or 'sills'), laccolites (or lenticular intrusions), and the still larger bosses out of which whole mountains may have been carved by denudation.

Volcanic Dykes.—The leading varieties of the volcanic rocks, basalt, andesite, and rhyolite, for example, are sometimes found in

Fig. 662.

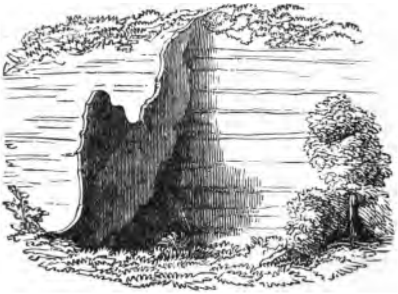


Basaltic dyke in the Val del Bove, Etna, from which a lava-stream is seen to proceed. (After Abich.)

dykes penetrating stratified and unstratified formations, and these are examples of *intrusive* or *subsequent* volcanic ejections. Fissures have already been spoken of as occurring in all kinds of rocks, some a few feet, others many yards in width. If such a parallel-sided fissure be filled with molten rock, or lava, the material on consolidation forms a wall-like mass known as a dyke. In volcanic cones it is sometimes possible to trace the actual connection between a dyke filling a fissure in the side of the volcano and a stream of lava which has flowed out at the surface (see fig. 662). It is not uncommon to

find such dykes passing through strata of soft materials, such as tuff, scoriæ, or shale, which, being more easily removed by denudation than the volcanic rock, are often washed away by the sea, rivers, or rain, in which case the dyke stands out prominently on the face of precipices, or on the level surface of a country, as may be seen in Madeira (see fig. 663) and in many parts of Scotland.

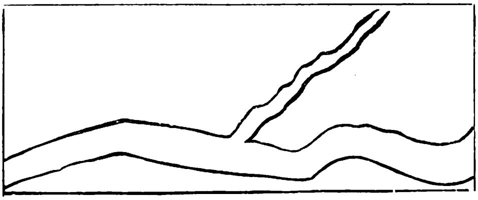
Fig. 663.



Dyke in valley, near Brazen Head, Madeira. (From a drawing by Basil Hall.)

In the islands of Arran and Skye, and in other parts of Scotland, where sandstone, conglomerate, and other hard rocks are traversed by lava-dykes, the converse of the above phenomenon is also seen. The dyke, having decomposed more rapidly than the containing rock, has once more left open the original fissure, often for a distance of many yards inland from the sea-coast. There is yet another case, by no means uncommon in Arran and other parts of Scotland, where the strata in contact with the dyke, and for a certain distance from it, have been hardened, so as to resist the action of the weather more

Fig. 664.



Ground plan of dolerite dykes traversing sandstone, Arran.

than the dyke itself or the surrounding rocks. When this happens, two parallel walls of indurated strata are seen protruding above the general level of the country and following the course of the dyke. In fig. 664 a ground-plan is given of a ramifying dyke of dolerite, cutting through sandstone on the beach near Kildonan Castle, in Arran. The larger branch varies from 5 to 7 feet in width, which will afford a scale of measurement for the whole.

Some volcanic dykes may be followed for leagues, uninterruptedly, in nearly a straight direction (like the Cleveland dyke, which runs from the Yorkshire coast right through the south of Scotland), showing that the fissures which they fill must have been of extraordinary length.

The materials of the dykes or flows which have been injected through and between strata were hot, pasty, and full of water and gases under pressure, and they acted upon and locally metamorphosed, more or less, the strata on either side and above and below them. The volcanic matter, moreover, became more or less crystalline on cooling. Usually, the sides and surfaces of such intrusive masses have a finer crystalline texture than the middle part, and occasionally the surfaces in contact with the strata are actually glassy. Columnar structure (the columns being at right angles to the walls of the dyke), spheroidal structure, and other forms of jointing occur in dykes. Some dykes are of composite character, different kinds of rocks entering into their composition. In certain cases a segregative action appears to have gone on within the molten material filling a dyke, and the sides and centre thus come to be formed of rocks of different chemical composition. In other cases a dyke has been reopened, and the fissure or fissures formed in it may be injected with materials of a different composition from that of the original dyke.

Rocks altered by volcanic dykes.—*Contact Metamorphism.* After these remarks on the form and composition of dykes themselves, it may be well to describe the alterations which they sometimes produce in the rocks in contact with them. The changes are usually such as the heat of melted matter and of the entangled steam and gases might be expected to cause. In some instances, however, little or no change happened in the surrounding rocks.

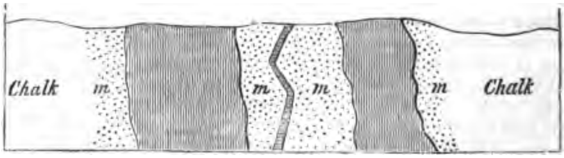
Plas-Newydd: Dyke cutting through shale.—A striking example of contact metamorphism, near Plas-Newydd, in Anglesea, has been described by Henslow. The dyke is 134 feet wide, and consists of dolerite. Strata of shale and argillaceous limestone, through which it cuts perpendicularly, are altered to a distance of 30, or even, in some places, of 35 feet from the edge of the dyke. The shale, as it approaches the igneous rock, becomes gradually more compact, and is most indurated where nearest the junction. Here it loses part of its laminated structure, but the bedded character is still discernible. In several places the shale is converted into hard porcellanous jasper. In the most hardened part of the mass, the fossil shells, principally *Producti*, are nearly obliterated; yet even here their impressions may frequently be traced. The argillaceous limestone undergoes analogous changes, losing its original texture as it approaches the dyke, and becoming granular and crystalline. But the most extraordinary phenomenon is the appearance in the shale of numerous crystals of analcime and garnet, which are seen to be confined to those portions of the rock affected by the dyke. Some of the garnets contain as much as 20 per cent. of lime, which they may have derived from the decomposition of the fossil shells. The same mineral has been observed, under very analogous circumstances, in High Teesdale, by Professor Sedgwick, where it also occurs in shale and limestone, altered by basalt.

Antrim: Dyke cutting through chalk.—In several parts of the county of Antrim, in the north of Ireland, Chalk with flints is

traversed by basaltic dykes. The chalk is there converted into granular marble near the basalt, the change sometimes extending 8 or 10 feet from the wall of the dyke, being greatest near the point of contact, and thence gradually decreasing till it becomes evanescent. 'The extreme effect,' says Dr. Berger, 'presents a dark brown crystalline limestone, the crystals running in flakes as large as those of coarse primitive (metamorphic) limestone; the next state is saccharine, then fine-grained and arenaceous; a compact variety, having a porcellanous aspect and a bluish-grey colour, succeeds: this, towards the outer edge, becomes yellowish white, and insensibly graduates into the unaltered chalk. The flints in the altered chalk usually assume a grey yellowish colour.' All traces of organic remains are effaced in that part of the limestone which is most crystalline.

The annexed drawing (fig. 665) represents three basaltic dykes traversing the chalk, all within the distance of 90 feet. The chalk contiguous to the two outer dykes is converted into a finely granular marble, *m m*, as are the whole of the masses between the outer dykes and the central one. In some cases the change undergone by the chalk is of a chemical nature, and the rock, besides being indurated

Fig. 665.



Basaltic dykes in chalk in Island of Rathlin, Antrim.
Ground plan as seen on the beach. (Conybeare and Buckland.)

and crystallised, is also dolomitised. The complete contrast in the composition and colour of the intrusive and invaded rocks in these cases renders the phenomena peculiarly clear and interesting. Another of the dykes of the north-east of Ireland has converted a mass of red sandstone into hornstone. By another, the shale of the Coal-measures has been indurated, assuming the character of flinty slate; and at Portrush the shaly clay of the Lias has been changed into flinty slate, which still retains numerous impressions of *Ammonites*. In the infancy of geological science the aqueous origin of basalt was maintained by Werner and his disciples. They mistook the altered Lias clay of Antrim for basalt, and referred to the occurrence of *Ammonites* in the rock as a proof that this rock could not be of igneous origin.

It might have been anticipated that beds of coal would, from their combustible nature, be affected in an extraordinary degree by the contact of melted rock. This is seen to be the case in one of the doleritic dykes of Antrim, which, passing through a bed of coal, reduces it to a cinder for the space of 9 feet on each side. At Cockfield Fell, in the North of England, a similar change is observed. Specimens taken at the distance of about 30 yards from the dyke

are not distinguishable from ordinary pit-coal; those nearer the dyke are like cinders, and have all the character of coke, while those close to it are converted into a substance resembling soot.

It is by no means uncommon, however, to meet with similar rocks almost wholly unchanged in the proximity of volcanic dykes. This great inequality in the effects of the igneous rocks may often arise from an original difference in their temperature, and in the nature of the entangled gases—such as is ascertained to prevail in different lavas, or in the same lava near its source and at a distance from it. Sometimes the extreme alteration produced near a volcanic dyke may be ascribed to the circumstance that the fissure now filled with solid rock may have constituted a channel through which enormous quantities of molten material have flowed up to the surface during vast periods of time.

Interbedded or Contemporaneous Flows.—Lava-streams—consisting of volcanic rock which has flowed over the surface and altered the underlying rocks—are scoriaceous in their upper part, and usually at their lower surface also. Sedimentary deposits accumulated upon the flows are of course not found to be altered physically or chemically by the contact, for before they were deposited the volcanic flow had cooled. Such flows are said to be interbedded. They may have occurred during the progress of the deposition of strata all around, during any particular geological period, and the fossils of the bed below and above the volcanic flow may be of the same species. Hence the flow thus interbedded is said to be contemporaneous.

Interbedded or contemporaneous flows occur as compact sheets or as fragmental masses, and they conform to the plane of the underlying stratum. They are not found to have broken into or altered the overlying strata in any way. Both of their surfaces are scoriaceous or vesicular, and this peculiarity may extend through the whole sheet. Beds of tuff and other fallen materials may be interstratified with the flows.

Fig. 666.

Interstratified volcanic tuff and shale. (After Geikie.)

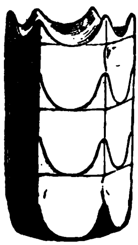
The fragmentary volcanic rocks of the present day, such as ashes and blocks, fall on the surface and do not influence the underlying strata. In past geological periods the tuffs and ash-beds and the breccias similarly covered other rocks in vast deposits, more or less stratified, and no metamorphism resulted.

In the illustration (fig. 666), from the Lower Carboniferous rocks of Linlithgowshire, a black shale (1) is at the bottom, and has the remains of terrestrial plants; and there are other shales, numbered 3, 5, 7, 9. Between them are bands of pale yellowish volcanic tuff with lapilli or ejected pieces of an older lava (Nos. 2, 4, 6, 8). A coarse agglomerate tuff lies on the top of all (No. 10).

The distinction between volcanic materials which have accumulated

on land and on the sea-floor respectively is often not very easy. Tuffs or volcanic ashes collect on the floor of the Mediterranean, and are dredged up with the living mollusca, and lava-currents have, during historical times, flowed into the Bay of Naples, and have become columnar in their structure. Intrusive volcanic sheets are distinguished from contemporaneous or interbedded lava flows by not exhibiting scoriaceous upper and under surfaces; by their affecting by contact metamorphism the strata *above* as well as below them; by their usually more crystalline and less scoriaceous character; and by the fact that they often are seen to cut across and to send offshoots into surrounding beds.

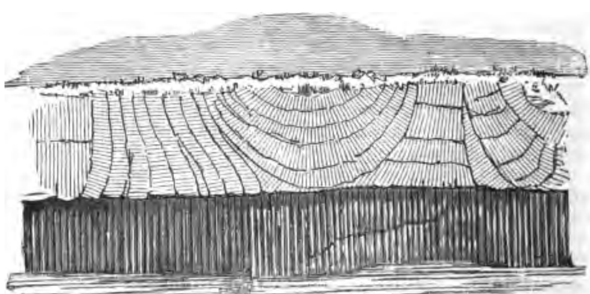
Fig. 667.



Basaltic column, divided by curved cross joints and with 'ball-and-socket'-articulations.

Columnar and globular structure.—One of the characteristic forms assumed by volcanic rocks is the columnar, a structure often displayed in a very striking manner by basaltic lavas. The columns are sometimes straight, at other times curiously curved and twisted. In section they are polygonal (with a tendency towards hexagonal forms), and they are often divided longitudinally by equidistant joints, which sometimes exhibit curved surfaces of articulation; in certain cases the angles of one division of a column are found to project and to form processes which fit into sockets in the adjoining divisions (see fig. 667). Columns of different varieties often occur in the

Fig. 668.



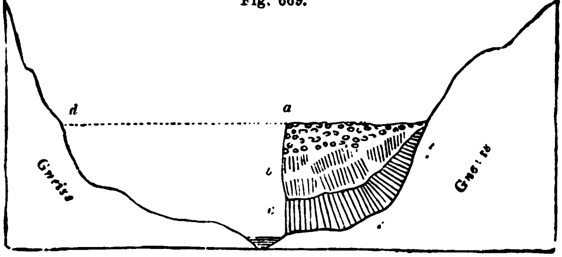
Lava-stream cut through in the valley of the Ardèche, with thick vertical columns in its lower part, and thinner columns, irregularly disposed, in its upper part. (After Scrope.)

same lava stream, the thick straight articulated columns being found in the lower, and the smaller curved forms in the upper portion; and the line of junction between the two kinds is in many cases very distinctly marked (see fig. 668). It is this peculiar combination of columns of different kinds which gives rise to the beautiful and

well-known features of the Isle of Staffa; it is also seen in many lavas of more recent date.

It being assumed that columnar rock has consolidated from a fluid state, the prisms are found to be always at right angles to the *cooling surfaces*. If these surfaces, therefore, instead of being either perpendicular or horizontal, are curved, the columns ought to be inclined at every angle to the horizon; and there is a beautiful exemplication of this phenomenon in one of the valleys of the

Fig. 669.



Lava of La Coupe d'Ayzac, near Antraigue, in the Department of Ardèche.

Vivarais, a mountainous district in the South of France, where, in the midst of a region of gneiss, a geologist encounters unexpectedly several volcanic cones of loose sand and scoriæ. From the crater of one of these cones, called La Coupe d'Ayzac, a stream of lava has descended and occupied the bottom of a narrow valley, except at those points where the river Volant, or the torrents which join it, have cut away portions of the solid lava. The accompanying sketch (fig. 669) represents the remnant of the lava at one of these points. It is clear that the lava once filled up the whole valley to the dotted line *d a*; but the river has gradually swept away all below that line, while the tributary torrent has laid open a transverse section; by which we perceive, in the first place, that the lava is composed, as is usual in that district, of three parts: the uppermost, at *a*, being scoriaceous; the second, *b*, presenting irregular prisms of small diameter; and the third, *c*, with regular columns of great thickness, which are vertical on the banks of the Volant, where they rest on a horizontal base of gneiss, but which are inclined at an angle of 45° at *g*, and are nearly horizontal at *f*, their position having been everywhere determined, according to the law before mentioned, by the form of the original valley.

Fig. 670.

Columnar basalt in the Vicentin. (Fortis.)

In fig. 670, on the preceding page, a view is given of some of the inclined and curved columns which present themselves on the sides of the valleys in the hilly region north of Vicenza, in Italy, and at the foot of the higher Alps. Unlike those of the Vivarais, last mentioned, the basalt of this country was evidently submarine, and the present valleys have since been hollowed out by denudation. In vertical dykes, as has been already remarked, the columns are horizontal; they start from the outer walls of the dyke, and meet in an irregular line towards its centre.

The columnar structure is by no means peculiar to the volcanic rocks of the basaltic type; it is also observed in trachyte, and other more acid rocks, although in these it is rarely exhibited in such regular polygonal forms, and never with the ball-and-socket joints, which form so conspicuous a feature in many basaltic columns. It has been already stated that basaltic columns are often divided by cross-joints. Sometimes each segment, instead of an angular

Fig. 671.

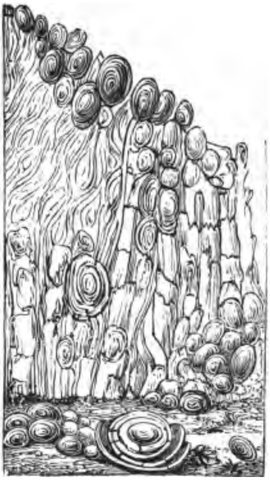
Basaltic pillars of the Käsegrotte, Bertrich-Baden, halfway between Trèves and Coblenz. Height of grotto, from 7 to 8 feet.

assumes a spheroidal form, usually produced by weathering, so that a pillar is made up of a pile of balls, usually flattened, as in the Cheese-grotto at Bertrich-Baden, in the Eifel, near the Moselle (fig. 671). The basalt there is part of a small stream of lava, from 30 to 40 feet thick, which has proceeded from one of several volcanic craters, still extant, on the neighbouring heights.

In some masses of decomposing basalt, dolerite, and other volcanic rocks, the globular structure is so conspicuous that the rock has the appearance of a heap of large cannon-balls. According to M. Delesse, the middle of each spheroid has been a centre of contraction produced by cooling; Professor Bonney has assigned the globular, 'curvitabular,' and other structures exhibited in volcanic rocks to the same cause. To similar contraction we may attribute some cases of columnar structure in sedimentary strata, such as volcanic ash, shale and sandstone, which have been affected by the proximity of volcanic dykes or the overflow of lava-streams.

Scrope gives as an illustration of this structure a glassy rhyolite or 'pitchstone-porphyry' in one of the Ponza islands, which rise from the Mediterranean, off the coast of Terracina and Gaeta. The globes vary from a few inches to three feet in diameter, and are of an ellipsoidal form (see fig. 672). The whole rock is in a state of decomposition, 'and when the balls have been exposed a short time to the weather, they scale off at a touch into numerous concentric coats, like those of a bulbous root, inclosing a compact nucleus. The laminæ of this nucleus have not been so much loosened by decomposition; but the application of a ruder blow will produce a still further exfoliation.' This spheroidal structure may be also seen in volcanic ash at Burntisland and in many other rocks; the perlitic structure, before referred to, is an example of the same kind of action exhibited on a very minute scale in rocks of vitreous texture.

Fig. 672.



Globiform pitchstone. Chiaja di Luna, Isle of Ponza. (Scrope.)

For further information on the nature of volcanic action, Scrope's 'Volcanoes' may be consulted, and the volume on the same subject in the 'International Scientific Series.'

CHAPTER XXXII

PRINCIPLES ON WHICH THE CHRONOLOGICAL CLASSIFICATION OF VOLCANIC ROCKS IS BASED

Variations of mineral character in the volcanic rocks of different periods—Not essential, but due to alteration—Age of lava flows and intrusions—Tests to be applied to determine relative age of volcanic masses—Sources of error in drawing inferences—Great value of fossils when found—Test by included fragments—Order in which volcanic rocks have been erupted—Views of Bunsen, Durocher, Richthofen, and later authors.

Age of volcanic phenomena.—Having in the former part of this work referred the sedimentary strata to a long succession of geological periods, we have now to consider how far the volcanic formations can be classed in a similar chronological order. The tests of relative age in this class of rocks are four: 1st, superposition or intrusion, with or without alteration of the

rocks in contact; 2nd, organic remains; 3rd, mineral characters; 4th, included fragments of older rocks.

Besides these four tests it may be said, in a general way, that volcanic rocks of pre-Palæozoic and Palæozoic age differ, in a certain degree, from those of the Secondary or Mesozoic age, and these again from the Tertiary and Recent. Not, perhaps, that they differed originally in a much greater degree than the modern volcanic rocks of one region, such as that of the Andes, differ from those of another, such as Italy, but because all rocks permeated by water, especially if its temperature be high, are liable to undergo a slow metamorphosis.

Although subaërial and submarine denudation removes, in the course of ages, large portions of the cones and of the upper or more superficial products of volcanoes, yet these are sometimes preserved by the occurrence of subsidence, and the burying of the volcanic rocks under sedimentary deposits. In this way the volcanic structures may be protected for ages; but even in this case they will not remain unaltered, because they are percolated by water, often at high temperatures, and charged with silica, iron-salts, and other substances in solution, whereby gradual changes in the constitution of the rocks are induced. Every geologist is aware how often silicified trees occur in volcanic tuffs, the perfect preservation of their internal structure showing that they had not decayed before the petrifying material was supplied.

The porous and vesicular nature of a large part, both of the basaltic and trachytic lavas, affords cavities in which silica, calcite, and the zeolites are readily deposited. The minerals of the zeolite family, which are so commonly found in such amygdaloidal cavities, are closely related in composition to the felspars, but contain water. Daubrée and others have shown that the zeolites are formed by the action of percolating water upon the felspathic ingredients of rocks. From these considerations it follows that perfect identity of appearance and character in very ancient and very modern volcanic formations is scarcely to be expected.

Age of intrusive dykes or sheets.—After the differences between intrusive and contemporaneous volcanic flows have been considered (see p. 479), there should be no difficulty in understanding the relation of the age of strata and of the flows which pass through or amongst or above them, especially when the strata are capable of being classified in definite geological groups or formations.

The nearly vertical dykes and the more or less horizontal sheets must be younger than the strata they penetrated and

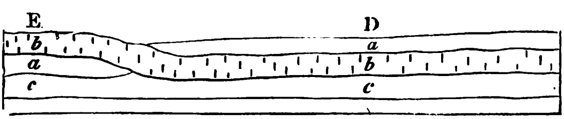
influenced physically and chemically. *How much* younger does not always appear, because, for instance, a dyke which was formed in Tertiary times may come to the surface of the earth through Carboniferous strata which now form the surface rock there, denudation having worn away the overlying strata before or since the intrusion took place. A careful survey of the general distribution of the strata around the volcanic area, however, will often enable the question of age to be settled.

Age of interbedded or contemporaneous lava flows.—The flow must be younger than the stratum it overlies, and has metamorphosed more or less, and older than the stratum which rests on its scoriaceous upper surface. The fossils in the two sets of strata determine their age and the relative antiquity of the flow. The presence of similar species in the two sets of strata proves the flow to have been truly contemporaneous, for the volcanic outburst was evidently only an episode in the history of the period.

The finding of very different species of fossils in the two sets of strata leads to a less definite conclusion regarding the age of the flow, which may be of any age between the ages of the underlying and overlying beds.

In the annexed figure (fig. 673) a flow, *b*, is placed under D, between the strata *a* and *c* of the Carboniferous formation. It appears to be interbedded and contemporaneous. But both the

Fig. 673.

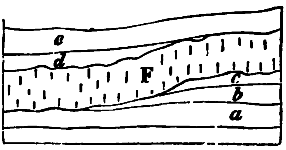


strata *a* and *c* have been more or less altered by it, so that it was injected subsequently to the deposition of both of them. Under E, the same flow covers *a*, having pierced it and baked it on the top. Hence this flow is certainly younger than *a*.

We may, however, be easily deceived in supposing the volcanic rock to be intrusive, when in reality it is contemporaneous; for a sheet of lava, as it spreads over the bottom of the sea, cannot rest everywhere upon the same stratum, either because these have been denuded, or because, if newly thrown down, they thin out in certain places, thus allowing the lava to cross their edges. Besides, the heavy igneous mass while fluid will often, as it moves along, cut a channel into beds of soft mud and sand. Suppose that the submarine lava F (fig. 674) has come in contact in this manner with the strata *a*, *b*, *c*, and that

after its consolidation the strata *d*, *e*, are thrown down in a nearly horizontal position, yet so as to lie unconformably to F, the appearance of subsequent intrusion will here be complete, although the lava is in fact contemporaneous. We must not, therefore, hastily infer that the rock F is intrusive, unless we find the overlying strata *d*, *e*, to have been altered at their junction, as if by heat.

Fig. 674.



The test of age by superposition is strictly applicable to all stratified volcanic tuffs, according to the rules already explained in the case of sedimentary deposits (see pp. 128, 129).

If masses of volcanic rock intercalated among strata have evidently participated in the movements that have produced the curvatures and fractures of the strata, the volcanic masses, even if intrusive in origin, must clearly be of more ancient date than the period when the movements that have affected the whole series of deposits took place.

Test of age by organic remains.—We have seen how, in the vicinity of active volcanoes, scoriæ, pumice, fine dust, and fragments of rock are thrown up into the air, and then showered down upon the land, or into neighbouring lakes or seas. In the tuffs so formed, shells, corals, or any other durable organic bodies which may happen to be strewn over the bottom of a lake or sea, will be embedded, and thus continue as permanent memorials of the geological period when the volcanic eruption occurred. Tufaceous strata thus formed in the neighbourhood of Vesuvius, Etna, and Stromboli, and other volcanoes now in islands or near the sea, may give information of the relative age of these tuffs at some remote future period when the activity of these mountains is extinguished. By evidence of this kind we can establish a coincidence in age between volcanic rocks and the different Palæozoic, Secondary, and Tertiary fossiliferous strata.

The tuffs alluded to may not always be marine, but may include, in some places, freshwater shells; in others, the bones of terrestrial quadrupeds. The diversity of organic remains in formations of this nature is perfectly intelligible, if we reflect on the wide dispersion of ejected matter during eruptions, such as that of the volcano of Coseguina, in the province of Nicaragua, January 19, 1835. Hot cinders and fine scoriæ were then thrown up to a vast height, and covered the ground as they fell to the depth of more than 10 feet for a distance of

8 leagues from the crater in a southerly direction. Birds, cattle, and wild animals were scorched to death in great numbers, and buried in ashes. Some volcanic dust fell at Chiapa, upwards of 1,200 miles, not to leeward of the volcano as might have been anticipated, but to windward, a striking proof of a counter-current in the upper region of the atmosphere; and some on Jamaica, about 700 miles distant to the north-east. In the sea, also, at the distance of 1,100 miles from the point of eruption, Captain Eden of the 'Conway' sailed 40 miles through floating pumice, among which were some pieces of considerable size. The importance of studying the fossils contained in the strata beneath and above contemporaneous flows has been already pointed out.

Test of age by mineral composition.—As sediment of homogeneous composition, when discharged from the mouth of a large river, is often deposited simultaneously over a wide area, so a particular kind of lava flowing from a crater during one eruption may spread over an extensive district; thus in Iceland, in 1783, the melted matter, pouring from Skaptár Jokul, flowed in streams in opposite directions, and formed a continuous mass, the extreme points of which were 90 miles distant from each other. This enormous current of lava varied in thickness from 100 feet to 600 feet, and in breadth from that of a narrow river-gorge to 15 miles. Now, if such a mass should afterwards be divided into separate fragments by denudation, we might still perhaps identify the detached portions by their similarity in mineral composition. Nevertheless, this test will not always avail the geologist; for, although there is usually a prevailing character in lava emitted during the same eruption, and even in the successive currents flowing from the same volcano, still, in many cases, the different parts even of one lava-stream, or, as before stated, of one continuous mass of lava, vary much in mineral composition and texture.

Test by included fragments.—Where the evidence of superposition alone would be insufficient, we may sometimes discover the relative age of two sets of volcanic rocks, or of an aqueous deposit and the volcanic rock on which it rests, by finding fragments of one included in the other. It is also not uncommon to find a conglomerate almost exclusively composed of rolled pebbles of lava, associated with some fossiliferous stratified formation in the neighbourhood of igneous rock-masses. If the pebbles agree, generally, in mineral character with the latter, we are then enabled to determine its relative age by knowing that of the fossiliferous strata associated with the conglomerate. The origin of such conglomerates is explained by

observing the shingle beaches composed of pebbles of igneous rock in modern volcanoes, as at the base of Etna.

Order of appearance of different volcanic rocks.—In Auvergne, the Eifel, and other countries where acid and basic lavas are both present, the acid rocks are *for the most part* older than the basaltic. These rocks do, indeed, sometimes alternate to some extent, as in the volcano of Mont Dore, in Auvergne; and in Madeira, acid rocks overlie an older basic series; but the acid rock occupies more generally an inferior position, and is cut through and overflowed by basalt. It seems that in each region where a long series of eruptions have occurred, the lavas containing quartz and acid felspar have been first emitted, and the escape of the more basic kinds has followed.

Von Richthofen, who has given the subject of the succession of volcanic materials in North America and Europe great attention, believed that the volcanic rocks might be arranged in five groups, and that their appearance has been in the same order all over the world:—1, Propylite; 2, Andesite; 3, Trachyte; 4. Rhyolite; 5, Basalt. Basalt, he affirmed, is always the last of a series, although some of the other groups may not have been present. The explanation of the eruption of acid volcanic materials in the first instance, and of basic rocks subsequently, may be that —as suggested by Bunsen, Durocher, and later authors—a differentiation of molten materials within the earth's crust may take place, and the upper and lighter materials may be ejected before the lower and denser ones.

CHAPTER XXXIII

VOLCANIC ROCKS OF CAINOZOIC AGE

The latest exhibitions of volcanic energy in the British Islands—The thermal springs of Bath, &c.—Tertiary volcanoes of the west of Scotland and the north of Ireland—First period of eruption—Second period of eruption—Third period of eruption—Tertiary volcanic rocks of other parts of Europe—Vesuvius—Auvergne—Newer Pliocene volcanoes of Italy—Older Pliocene volcanoes of Italy and the Eifel—Oligocene and Miocene volcanoes of Auvergne and the Eifel—Eocene volcanic rocks of Monte Bolca—Tertiary volcanic rocks of the Atlantic Islands—Of India—The United States and Australia.

Latest exhibitions of volcanic activity in the British Islands.—We shall now select examples of contemporaneous volcanic rocks of successive geological periods, to show that igneous causes have been in activity in all past ages of the world.

They have been perpetually shifting the places where they have broken out at the earth's surface, and we can sometimes prove that those areas which are now the great theatres of volcanic activity were in a state of perfect tranquillity at remote geological epochs; while, on the other hand, in places where at former periods the most violent eruptions took place at the surface and continued for a great length of time, there has been an entire suspension of igneous action in historical times. The most recent volcanic rocks in the British Islands are those occurring in the Hebrides and the North of Ireland, and they rest upon strata containing Upper-Chalk fossils. They are products of three more or less distinct periods of eruption, which all clearly belong to the Tertiary era; but in the absence of intercalated strata containing marine fossils it is not possible to determine their exact position in the geological series. The lavas of the second period of eruption are found alternating with clays containing the leaves and other remains of terrestrial plants. There seems to be no reason to doubt that these belong to the Older-Tertiary period, and some palæophytologists are inclined to assign them to a very early part of that period. Considering, however, the difficulty of exactly correlating geological deposits by the evidence of land-plants only—especially when that evidence consists almost entirely of detached leaves—it is perhaps not wise to do more than assign the first two periods of eruption to the Older Tertiary. In the interval between the second and third periods of eruption great denudation took place, and there was probably a considerable lapse of time—so there is little doubt that the third period of eruption must have fallen within the Newer-Tertiary period. The fact that all traces of cones and craters have been removed, and that only very bulky lava-streams, or the centres of volcanic cones of considerable size, have been preserved, points to the conclusion that a long period of time must have elapsed since these latest British volcanoes became extinct. Of volcanic action we find no trace in the British Islands at the present day beyond certain hot springs, like that of Bath. This spring has a constant temperature of from 117° to 120° F., it contains about 144 grains per gallon of mineral matter in solution, and it has certainly flowed since Roman times. As illustrating how much may be effected by slow continuous action, as contrasted with violent and spasmodic activity, it may be interesting to refer to calculations which have been made by Lyell and Ramsay concerning the effects produced by the Bath spring in historical times. It is probable that this comparatively small thermal spring has relieved the earth's crust, in 2,000 years, of as much heat as was dissipated in the

eruption forming Monte Nuovo during three days in 1538. Nor was the actual amount of matter brought from the earth's interior and deposited on its surface by the Bath spring, less than that resulting from the outburst that produced the Monte Nuovo; but while, in the latter case, the materials were piled up round the volcanic orifice, and remain to our view, in the former they were carried into the Avon, from the Avon into the Severn, and by the latter delivered to the ocean.

The Tertiary Volcanoes of the British Islands.—The volcanic area stretching through the North of Ireland and the inner Hebrides belongs to a 'petrographic province,' which is prolonged northwards and includes both the Faroe Islands and Iceland. While volcanic activity has died out in the southern part of this province, it is still rife in the extreme north, within the island of Iceland. It is possible that certain other rocks to the southward, like the granite of Lundy Island and the phonolite of the Wolf's Rock, mark a still further extension of this area of volcanic activity in Tertiary times.

All through this 'petrographical province' the different kinds of rocks erupted exhibit remarkable analogies in character, and in the order in which they made their appearance. To use the expressive term suggested by Professor Iddings, there is a marked 'consanguinity' among the products emptied in different parts of the area.

First Period of Volcanic Activity.—The rocks ejected during the earliest period were of two kinds. *First*, great masses of andesitic lavas forming bulky lava-streams and belonging to the class of more basic pyroxene-andesites (augite-andesites, and enstatite-andesites) and the acid mica-andesites and hornblende-andesites; these andesites varied too, not only in their mineralogical constitution, but in their structure, and we find every gradation from stony to glassy types. As is so common in Auvergne and other districts, we sometimes find lavas of more basic types—true basalts—alternating with the andesitic flows. There were five great centres within the district of the Inner Hebrides from which these andesitic lavas were erupted and accumulated to form the basal portions of volcanoes of vast dimension. These centres of volcanic action are now found constituting the following districts—St. Kilda, the centre of the Isle of Skye, the Small Isles (Rum, Eigg, &c.), the peninsula of Ardnamurchan, and the Isle of Mull. At each of these centres there is evidence of great solfataric action having taken place, after the eruption of the andesitic lavas, and by this action the rocks in question were converted into the altered forms known as 'propylites.' It is interesting to note that, as pointed out by Von Richthofen, volcanic activity in the districts of Hungary and the Western Territories of North America commenced with the eruption of andesitic lavas and their conversion by solfataric action into propylites. In the North of Ireland, according to the researches of the geological surveyors of that country, the rocks erupted during this earliest period consisted mainly of basalts, which are found lying upon the eroded surface of the hard chalk (white limestone) of Antrim. Towards the close of this first period, materials of highly acid character were intruded into these andesitic lavas and the underlying rocks, and these consolidated

to form the great masses of granite, micropegmatite, and quartz-felsite, found at each of these five districts, and also in the island of Arran. These acid rocks are seen to send numerous veins into the andesites and to include fragments of them. The rocks erupted during the first period appear generally to have suffered so much denudation before the ejection of the materials of the second period, that there is some lack of evidence concerning the amount of material which actually reached the surface as lavas. Some masses of acid lavas (rhyolites), however, were certainly ejected in the Inner Hebrides at this time; and in Antrim there was formed the beautiful volcanic mass of Tardree and Sandy Bræs, consisting of rhyolites varying from very coarse-grained stony types (Nevadites) through many spherulitic and banded varieties to glassy forms (pitchstone-porphyry).

Second Period of Volcanic Activity.—The *second* period of volcanic eruption within the British Islands during the Tertiary period was marked by the outflow of immense sheets of basaltic lava, which accumulated to a great thickness—in places exceeding 2,000 feet. These basaltic lavas strikingly resemble the rocks of the same composition in the Faroe Islands and Iceland, and like them often exhibit the ophitic structure (see fig. 688, p. 518); they only rarely alternate with other lavas of more acid composition (andesites). That these lavas were poured out from the same great vents as gave rise to the older andesitic lavas (now converted into propylites) there is no room for doubting. The basaltic lavas, it is true, were of a more liquid character and spread farther from the centres of eruption than did the andesitic streams; but in this respect they strikingly resemble the modern basalts of Iceland and the Sandwich Islands. There is clear evidence, however, that, as in Etna, the basalts were not always ejected from the central vents of the great volcanoes of the period, but from parasitical cones on the flanks of the mountains; and a little to the north of Tobermory, in Mull, we find evidence of one such parasitical cone of exceptional dimensions, the plug of lava consolidated in the vent of the volcano being clearly traceable.

There is no evidence that any of the volcanic rocks ejected during the first period of activity were thrown out beneath the waters of the ocean—all traces of tuffs with marine remains being wanting. That the rocks of the second period were of subaërial origin there can be no doubt, for the basaltic lavas alternate with beds of tuff, river gravels, beds of lignite and old soils (burnt to a red colour by the heat of the lava), with other evidences of lacustrine, fluviatile, and terrestrial conditions. Some of the lakes in Ireland and Scotland which existed during this period contain deposits of a pisolitic ironstone, evidently formed by the action of organisms like those which at the present day form the lake-ores of Sweden (see p. 49).

The plant-remains found in the strata intercalated with the basalts of this second period consist of the living fern *Onoclea sensibilis*, L., with forms of *Thuja*, *Sequoia*, *Gingko*, *Platanus*, *Corylus*, &c., similar to those found in beds alternating with the basalts of Greenland, and having decidedly American affinities. The late Professor Heer regarded this flora as a Miocene one, while Mr. Starkie Gardner is disposed to refer it to the Montian or very oldest Eocene. In the present state of our knowledge it is probably not safe to attempt any more exact correlation of these strata than is

involved in placing them in the Older Tertiary. At the end of this second period of activity, the five great volcanoes of the Hebrides probably rivalled Etna in their dimensions.

Third Period of Volcanic Activity.—The *third* period of eruption was characterised by a great variety of volcanic products. Very acid rocks (rhyolites), with many different types of andesite and basalt, appeared in numerous sporadic outbursts usually thrown up to form lines of 'puys' like those of Auvergne, radiating from the five great centres which had become extinct. Most of the rhyolites appeared to have belonged to the class of soda-rhyolites or quartz-pantellerites, and these exhibit many interesting and glassy varieties. The andesites also are sometimes represented by beautiful glassy (vitrophyric) forms. As a rule, it is found that, owing to extensive denudation, the surface ejections from the youngest British volcanoes have all disappeared, and we can study only the fissures along which these eruptions took place—these, being filled with consolidated rock, constitute dykes of rhyolite, andesite, and basalt. Such dykes of rhyolite, both stony and glassy, are found traversing the granites, and all the other rocks in the Isle of Arran, and some of these belong to the class of 'composite dykes' (see p. 477). Certain of the andesite dykes, like those of Eskdale, and some of the basalt dykes, like that of Cleveland, can be traced cutting across rocks of all ages for more than one hundred miles, and these bear witness to the great length of the chains of 'puys' which were formed on lines radiating from the great volcanoes of the earlier periods of eruption.

In a few exceptional cases, where the volcanoes were of larger size, more considerable relics have escaped denudation. Thus at Beinn Shiant, in Ardnamurchan, we find numerous lava-streams, of both stony and glassy augite-andesite, with great beds of volcanic tuff preserved under these sheets of hard lava, the whole forming the basal relic of a by no means insignificant volcano. In the Island of Eigg the remains of two streams of glassy lava which have flowed in succession down the same valley, cut in the basalts of the second period of eruption, and covered beds of gravel derived from it, have been described by Hugh Miller and Sir Archibald Geikie. Unfortunately the only organic remains preserved in this gravel are fragments of coniferous wood, which have been named *Pinites eiggensis* by Witham, so that the exact geological age of these latest volcanic rocks of the British Islands remains doubtful.

TERTIARY VOLCANIC ROCKS OF THE EUROPEAN CONTINENT

Latest Exhibitions of Volcanic Activity in Europe.—Besides the volcanoes of Iceland, there are at present five active volcanoes on the shores or islands of the European continent—namely Etna, Vesuvius, Stromboli, Vulcano, and Santorin. But several submarine eruptions have occurred in recent years in the Mediterranean; and in various parts of Italy, Hungary, Germany, and France numerous thermal springs bear testimony to the fact that the igneous forces, though dormant, are not extinct in the area.

One portion of the lavas, tuffs, and trap-dykes of Etna, Vesuvius, the island of Ischia, and the Lipari Islands has been produced within the historical era; another and a far more considerable part originated at times immediately antecedent, when the waters of the Mediterranean were already inhabited by the existing species of mollusca, but when certain species of Elephant, Rhinoceros, and other quadrupeds, now extinct, inhabited Europe.

Vesuvius.—In the 'Principles of Geology' the history of the changes which the volcanic region of Campania is known to have undergone during the last 2,000 years has been traced. The aggregate effect of igneous operations during that period is far from insignificant, comprising as it does the formation and the repeated reconstruction of the modern cone of Vesuvius since the year 79, and the production of several minor cones in Ischia, together with that of Monte Nuovo in the year 1538. Lava-currents have also flowed upon the land and along the bottom of the sea; volcanic sand, pumice, and scoriæ have been showered down so abundantly that whole cities were buried; tracts of the sea have been filled up or converted into shoals; and tufaceous sediment has been transported by rivers and land-floods to the sea. There are also proofs, during the same recent period, of a permanent alteration of the relative levels of the land and sea in several places, and of the same tract having, near Puzzuoli, been alternately upheaved and depressed to the amount of more than 20 feet. In connection with these convulsions, there are found, on the shores of the Bay of Baiæ, recent tufaceous strata, filled with articles fabricated by the hands of man, and mingled with marine shells.

It has also been stated, that when we examine this same region, it is found to consist largely of tufaceous strata, of a date anterior to human history or tradition, which are of such thickness as to constitute hills from 500 to more than 2,000 feet in height. Some of these strata contain marine shells which are exclusively of living species, others contain a slight mixture (1 or 2 per cent.) of species not known as living.

The ancient part of Vesuvius is called Somma, and consists of the remains of an older cone which was partly destroyed by the first historic explosion (see fig. 648, p. 468).

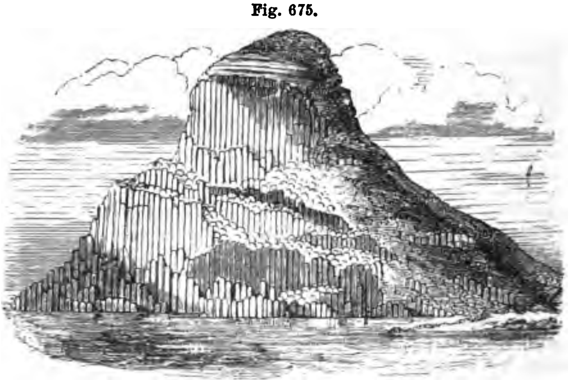
Auvergne. — Although the latest eruptions in Central France seem to have long preceded the historical era, they are so modern as to have a very intimate connection with the present superficial outline of the country and with the existing valleys and river-courses. Among a great number of cones with perfect craters, one called the Puy de Tartaret sent forth a lava current which can be traced up to its crater and which flowed for a distance of 13 miles along the bottom of the present valley to the village of Nechers, covering the alluvium of the old valley in which were preserved the bones of an extinct species of horse, and of a lagomys and other quadrupeds all closely allied to recent animals, while the associated land-shells were of species now living, such as *Cyclostoma elegans*, Drap., *Helix hortensis*, List., *H. nemoralis*, L., *H. lapicida*, Müll., and *Clausilia rugosa*, Drap. That the current which has issued from the Puy de Tartaret may, nevertheless, be very ancient in reference to the events of human history, we may conclude, not only from the divergence of the mammalian fauna from that of our day, but from the fact that a Roman bridge of such form and construction as continued in use only down to the fifth century, but which may be older, is now seen at a place about a mile and a half from St. Nectaire. This ancient bridge spans the river Couze with two arches, each about 14 feet wide. These arches spring from the lava of Tartaret, on both banks, showing that a ravine precisely like that now existing had already been excavated by the river through that lava thirteen or fourteen centuries ago.

Puy de Côme.—The Puy de Côme and its lava-current, near Clermont, may be mentioned as another minor volcano of about the same age. This conical hill rises from the granitic platform, at an angle of between 30° and 40°, to the height of more than 900 feet. Its summit presents two distinct craters, one of them with a vertical depth of 250 feet. A stream of lava takes its rise at the western base of the hill, instead of issuing from either crater, and descends the granitic slope towards the present site of the town of Pont Gibaud. Thence it pours in a broad sheet down a steep declivity into the valley of the Sioule, filling the ancient river-channel for the distance of more than a mile. The Sioule thus dispossessed of its bed has worked out a fresh one between the lava and the granite of its western bank; and the excavation has disclosed, in one spot, a wall of columnar basalt about 50 feet high.

Newer Pliocene volcanic rocks.—The more ancient portion of Vesuvius and Etna originated at the close of the Newer Pliocene period, when less than ten, sometimes only one, in a hundred of the shells differed from those now living. In the case of Etna, it was before stated (p. 233) that Pleistocene formations occur in the neighbourhood of Catania, while the oldest lavas of the great volcano are Pliocene. These last are seen associated with sedimentary deposits at Trezza and other places on the southern and eastern flanks of the great cone.

Cyclopean Islands.—The Cyclopean Islands, called by the Sicilians 'dei Faraglioni,' in the sea-cliffs of which these beds of clay, lava, and tuff are laid open to view, are situated in the Bay of Trezza, and may be regarded as the extremity of a promontory severed from the mainland. Here numerous proofs are seen of submarine eruptions, by which the argillaceous and sandy strata were invaded and cut through, and tufaceous breccias formed. Enclosed in these breccias are many angular and hardened fragments of laminated clay in different states of alteration by heat, and intermixed with volcanic sands.

Fig. 675.



View of the Isle of Cyclops in the Bay of Trezza.
(Drawn by Capt. Basil Hall.)

The loftiest of the Cyclopean islets, or rather rocks, is about 200 feet in height, the summit being formed of a mass of stratified clay, the laminæ of which are occasionally subdivided by thin arenaceous layers. These strata dip to the N.W., and rest on a mass of columnar

lava (see fig. 675) in which the tops of the pillars are weathered, and so rounded as to be often hemispherical. In some places in the adjoining and largest islet of the group, which lies to the north-eastward of that represented in the drawing (fig. 675), the overlying clay has been greatly altered and hardened by the igneous rock, and occasionally contorted in the most extraordinary manner; yet the lamination has not been obliterated, but, on the contrary, rendered much more conspicuous by the indurating process.

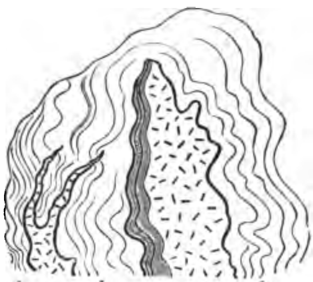
In the woodcut (fig. 676) is represented a portion of the altered rock, a few feet square, where the alternating thin laminæ of sand and clay are contorted in a manner often observed in ancient metamorphic schists. A great fissure, running from east to west, nearly divides this larger island into two parts, and lays open its internal structure. In the section thus exhibited, a dyke of lava is seen,

Fig. 676.

Contortions of strata in the largest of the Cyclopean Islands.

first cutting through an older mass of lava, and then penetrating the superincumbent tertiary strata. In one place the lava ramifies and terminates in thin veins, from a few feet to a few inches in thickness. The arenaceous laminæ are much hardened at the point of

Fig. 677.



Newer Pliocene strata invaded by lava. Isle of Cyclops (horizontal section).
a. Lava. *b.* Laminated clay and sand. *c.* The same altered.

contact, and the clays are converted into siliceous schist (fig. 677). In this island the altered rocks assume a honeycomb structure on their weathered surface, singularly contrasted with the smooth and even outline which the same beds present in their usual soft and yielding state.

Dykes of Palagonia.—Dykes of vesicular and amygdaloidal lava are also seen traversing marine tuff or peperino, west of Palagonia, some of the pores of the lava being empty, while others are filled with calcium carbonate. In such cases we may suppose the tuff to have resulted from showers of volcanic sand and scoriæ, together with fragments of limestone, thrown out by a submarine explosion similar to that which gave rise to Graham Island in 1831. When the mass was, to a certain degree, consolidated, it may have been rent open, so that the lava ascended through fissures, the walls of which were perfectly even and parallel. In one case, after the melted matter that filled the rent (fig. 678) had cooled down, it must have been fractured and shifted horizontally by a lateral movement.

In the second figure (fig. 679)

the lava has more the appearance of a vein, which forced its way through the peperino. It is highly probable that similar appearances would be seen, if we could examine the floor of the sea in that part of the Mediterranean where the waves have recently washed away the new volcanic island; for when a superincumbent mass of ejected fragments has been removed by denudation, we may expect to see sections of dykes traversing tuff, or, in other words, sections of the channels of communication by which the subterranean lavas reached the surface.

Crag of Suffolk, so well described by Mr. Searles Wood, the specific agreement between the British and Italian fossils is found to be so great, if we make due allowance for geographical distance and the difference of latitude, that we can have little hesitation in referring both to the same period, or to the Older Pliocene. It is highly probable that, between the oldest trachytes of Tuscany and the newest rocks in the neighbourhood of Naples, a series of volcanic products might be detected of every age from the Older Pliocene to the historical epoch.

Fig. 678.

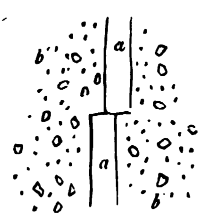
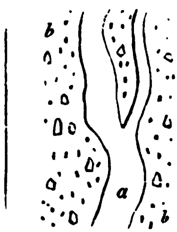


Fig. 679.



Ground-plan of dykes near Palagonia.

a. Lava. *b*. Peperino, consisting of volcanic sand, mixed with fragments of lava and limestone.

Older Pliocene Period. *Italy*.—In Tuscany, as at Radicofani, Viterbo, and Aquapendente, and in the Campagna di Roma, submarine volcanic tuffs are interstratified with the Older Pliocene strata of the Subapennine hills in such a manner as to leave no doubt that they were the products of eruptions which occurred when the shelly marls and sands of the Subapennine hills were in the course of deposition. These rocks are well known to rest conformably on the Subapennine marls, even as far south as Monte Mario in the suburbs of Rome. On the exact age of the deposits of Monte Mario new light has recently been thrown by a careful study of their marine fossil shells. After the comparison of no less than 160 species of shells with the shells of the Coralline

Pliocene Volcanoes of the Eifel. Some of the most perfect cones and craters in Europe may be seen on the left or west bank of the Rhine, near Bonn and Andernach. They exhibit characters distinct from those described in other volcanic districts, owing to the large part which the escape of aqueous vapour has played in the eruptions and the small quantities of lava emitted. The fundamental rocks of the district are grey and red sandstones and shales, with some associated limestones replete with fossils of the Devonian or Old Red Sandstone group. The volcanoes broke out in the midst of these inclined strata, and when the present systems of hills and valleys had already been formed. The eruptions occurred sometimes at the bottom of deep valleys, some-

times on the summit of hills, and frequently on intervening platforms. In travelling through this district we often come upon them most unexpectedly, and may find ourselves on the very edge of a crater before we had been led to suspect that we were approaching the site of any igneous outburst. Thus, for example, on arriving at the village of Gemund, immediately south of Daun, we leave the stream, which flows at the bottom of a deep valley in which strata of sandstone and shale crop out. We then climb a steep hill, on the surface of which we see the edges of the same strata dipping inwards towards the mountain. When we have ascended to a considerable height we see fragments of scoriæ sparingly scattered over the surface; until, at length, on reaching the summit, we find ourselves suddenly on the edge of a *tarn*, or deep circular lake basin, called the Gemunder Maar. In it we recognise the ordinary form of a crater, for which we have been prepared by the occurrence of scoriæ scattered over the surface of the soil. But on examining the walls of the crater we find precipices of sandstone and shale which exhibit no signs of the action of heat; and we look in vain for those beds of lava and scoriæ, dipping outwards on every side, which we have been accustomed to consider as characteristic of volcanic vents. As we proceed, however, to the opposite side of the lake, we find a considerable quantity of scoriæ and some lava, and see the whole surface of the soil sparkling with volcanic sand, and strewn with ejected fragments of half-fused shale which preserves its laminated texture in the interior, while it has a vitrified or scoriaceous coating.

Other crater-lakes of circular or oval form, and hollowed out of similar ancient strata, occur in the Upper Eifel, where copious aëriform discharges have taken place, throwing out vast heaps of pulverised shale into the air. I know of no other extinct volcanoes where gaseous explosions of such magnitude have been attended by the emission of so small a quantity of lava.

It appears that when some of these volcanoes were in action, the river valleys had already been eroded to their present depth.

Trass.—The tufaceous alluvium called *trass*, which has covered large areas in the Eifel, and choked up some old river valleys, now partially re-excavated, is unstratified. Its base consists almost entirely of pumice, in which are included fragments of basalt and other lavas, pieces of burnt shale, slate, and sandstone, and numerous trunks and branches of trees. If, as is probable, this trass was formed during the period of volcanic eruptions, it may have originated in the manner of the fetid mud ('moya') of the Andes.

We may easily conceive that a similar mass might now be produced, if a copious evolution of gases should occur in one of the lake-basins. If a breach were made in the side of the cone, the flood would sweep away great heaps of ejected fragments of shale and sandstone, which would be borne down into the adjoining valleys. Forests might be torn up by such a flood, and thus the occurrence of the numerous trunks of trees dispersed irregularly through the trass would be explained. The manner in which this trass conforms to the shape of the present valleys implies its comparatively modern origin, probably one dating no further back than the Pliocene period.

Oligocene.—*Rhine-Prussia.*—A large portion of the volcanic rocks of the Lower Rhine are coeval with the Oligocene deposits to which most of the 'Brown Coal' of Germany belongs. The Tertiary strata of that age are seen on both sides of the Rhine, in the neighbourhood of Bonn, resting unconformably on highly inclined and vertical strata of Silurian and Devonian rocks. The Brown-Coal formation of that region consists of beds of loose sand, sandstone, and conglomerate, clay with nodules of clay-ironstone, and occasionally flint. Layers of light brown

and sometimes black lignite are interstratified with the clays and sands, and often irregulary diffused through them. They contain numerous impressions of leaves and stems of trees, and are extensively worked for fuel, whence the name of the formation. In several places, layers of trachytic tuff are interstratified, and in these tuffs are leaves of plants identical with those found in the Brown Coal, showing that during the period of the accumulation of the latter, some volcanic products were ejected. The igneous rocks of the Westerwald, and of the mountains called the Siebengebirge, consist partly of basaltic and andesitic and partly of trachytic lavas, the latter being in general the more ancient. There are many varieties of trachyte, some of which are highly crystalline, resembling a coarse-grained granite, with large separate crystals of felspar. Trachytic tuff is also very abundant.

Miocene and Oligocene volcanic rocks of Auvergne. The extinct volcanoes of Auvergne and Cantal in Central France seem to have commenced their eruptions in the Oligocene period, but to have been most active during the Miocene and Pliocene eras.

The earliest monuments of the Tertiary period in that region are lacustrine deposits of great thickness, in the lowest conglomerates of which are rounded pebbles of quartz, mica-schist, granite, and other non-volcanic rocks, without the slightest intermixture of volcanic products. To these conglomerates succeed argillaceous and calcareous marls and limestones, containing Oligocene shells and bones of mammalia, the higher beds of which sometimes alternate with volcanic tuff of contemporaneous origin. After the filling up or drainage of the ancient lakes, huge piles of trachytic and basaltic rocks, with volcanic breccias, accumulated to a thickness of several thousand feet, and were superimposed upon granite, or the contiguous lacustrine strata. The greater portion of these igneous rocks appears to have originated during the Miocene and Pliocene periods; and extinct quadrupeds of those eras, belonging to the genera *Mastodon*, *Rhinoceros*, and others, were buried in ashes and beds of alluvial sand and gravel, which owe their preservation to overspreading sheets of lava.

In Auvergne, the most ancient and conspicuous of the volcanic masses is Mont Dore, which rests immediately on the granitic rocks standing apart from the freshwater strata. This great mountain rises suddenly to the height of several thousand feet above the surrounding platform, and retains the shape of a flattened and somewhat irregular cone, the slope of which is gradually lost in the high plain around. This cone is composed of layers of scoriæ, pumice, and fine detritus, with interposed beds of trachyte and basalt, which descend, often in uninterrupted sheets, until they reach and spread themselves round the base of the mountain. Conglomerates, also, composed of angular and rounded fragments of igneous rocks, are observed to alternate with the above; and the various masses are seen to dip off from the central axis, and to lie parallel to the sloping flanks of the mountain. The summit of Mont Dore terminates in seven or eight rocky peaks, where no regular crater can now be traced, but where we may easily imagine one to have existed, which may have been shattered by earthquakes, and have suffered degradation by aqueous agents. Originally, perhaps, like the highest crater of Etna, it may have formed an insignificant feature in the great pile, and, like it, may frequently have been destroyed and renovated.

Respecting the age of the great mass of Mont Dore, we cannot arrive at present at any positive decision, because no organic remains have yet been found in the tuffs, except impressions of the leaves of trees of species not yet determined. It has already been stated that the earliest eruptions must have been posterior in origin to those grits and conglomerates of the freshwater formation of the

Limagne which contain no pebbles of volcanic rocks. But there is evidence at a few points, that some eruptions took place before the great lakes were drained, while others occurred after the desiccation of those lakes, and when deep valleys had already been excavated through freshwater strata.

The valley in which the cone of Tartaret, before mentioned (p. 498), is situated affords an impressive monument of the very different dates at which the igneous eruptions of Auvergne have happened; for while the cone itself is of Pleistocene date, the valley is bounded by lofty precipices composed of sheets of ancient columnar trachyte and basalt, which once flowed from the summit of Mont Dore in some part of the Miocene period. These Miocene lavas had accumulated to a thickness of nearly 1,000 feet before the ravine was cut down to the level of the river Couze, a river which was at length dammed up by the modern cone and the upper part of its course transformed into a lake.

Eocene volcanic rocks. *Monte Bolca.*—The fissile limestone of Monte Bolca, near Verona, has for many centuries been celebrated in Italy for the number of perfect ichthyolites which it contains. When Lyell visited Monte Bolca, in company with Murchison, in 1828, it was ascertained that the fish-bearing beds were of Eocene date, containing well-known species of Nummulites, and that a long series of submarine volcanic eruptions, evidently contemporaneous, had produced beds of tuff, which are cut through by dykes of basalt. There is evidence here of a long series of submarine volcanic eruptions of Eocene date, and during some of them, as Sir R. Murchison has suggested, shoals of fish were probably destroyed by the evolution of heat, by noxious gases, and tufaceous mud, just as happened when Graham's Island was thrown up between Sicily and Africa in 1831, at which time the waters of the Mediterranean were seen to be charged with red mud, and covered with dead fish over a wide area.

TERTIARY VOLCANOES OF THE ATLANTIC ISLANDS

Upon the great ridge that traverses the Atlantic from north to south stand a number of volcanoes that were in eruption during the same periods as those of the Hebrides and the North of Ireland. The date of occurrence of the outbursts of certain of these volcanoes it has been possible to determine, in some cases from the fossils contained in beds intercalated with the lavas.

Madeira.—Although the more ancient portion of the volcanic eruptions by which the island of Madeira and the neighbouring one of Porto Santo were built up occurred in the Miocene period, a still larger part of the island is of Pliocene date. That the latest outbreaks belonged to the Newer Pliocene period is inferred from the close affinity to the present flora of Madeira of the fossil plants preserved in a leaf-bed in the north-eastern part of the island. These fossils, associated with some lignite in the ravine of the river San Jorge, can none of them be proved to be of extinct species, but their antiquity may be inferred from the following considerations. First—the leaf-bed, discovered by Lyell and Hartung in 1853, at the height of 1,000 feet above the level of the sea, crops out at the base of a cliff formed by the erosion of a gorge, cut through alternating layers of basalt and scoriæ, the product of a vast succession of eruptions of unknown date, piled up to a thickness of 1,000 feet, which were all poured out after the plants, of which about twenty species have been recognised, flourished in Madeira. These lavas are inclined at an angle of about 15° to the north, and came down from the great central region of eruption. Their accumulation implies a long period of intermittent volcanic action, subsequently to which the ravine

of San Jorge was hollowed out. Secondly—some few of the plants, though perhaps all of living genera, are supposed to be forms not now existing in the island. They have been described by Sir Charles Bunbury and Professor Heer, and the former first pointed out that many of the leaves are of the laurel type and analogous to those now flourishing in the modern forests of Madeira. He also recognised among them the leaves of *Woodwardia radicans*, Cav.? and *Davallia canariensis*, Smith, ferns now abundant in Madeira. Thirdly—fossil land shells, five per cent. of which are extinct, are found in the blown sands upon the leaf-bed.

Although the greater part of the volcanic eruptions of Madeira belong to the Pliocene period, the most ancient of them are of Miocene date, as is shown by the fossil shells included in the marine tuffs which have been upraised to the height of 1,300 feet above the level of the sea at San Vicente, in the northern part of the island. A similar marine and volcanic formation constitutes the fundamental portion of the neighbouring island of Porto Santo, forty miles distant from Madeira, and is there elevated to an equal height, and covered, as in Madeira, with lavas of subaërial origin.

The largest number of fossils have been collected from the tuffs and conglomerates and some beds of limestone in the island of Baizo, off the southern extremity of Porto Santo. The species amount, in this single locality, to more than sixty, of which about fifty are mollusca, but many are only casts. Some of the shells probably lived on the spot during the intervals between eruptions, and some may have been cast up into the water or air together with muddy ejections, and, falling down again, have been deposited on the bottom of the sea. The hollows in some of the fragments of vesicular lava, of which the breccias and conglomerates are composed, are partially filled with calcite, being thus half converted into amygdaloids. Among the fossil shells common to Madeira and Porto Santo, large Cones, Strombs, and Cowries are conspicuous among the univalves, and *Cardium*, *Spondylus*, and *Lithodomus* among the lamellibranchiate bivalves, while among the Echinoderms the large *Clypeaster altus*, L., an extinct European Miocene form, is found.

The largest list of fossils has been published by Karl Mayer in Hartung's 'Madeira.' Mayer identifies one-third of the Madeira shells with known European Miocene forms.

Grand Canary.—In the Canaries, especially in the Grand Canary, the same marine Upper Miocene formation is found. Stratified tuffs, with intercalated conglomerates and lavas, are there seen in nearly horizontal layers in sea-cliffs about 300 feet high near Las Palmas. Lyell and Hartung were unable to find marine shells in these tuffs at a greater elevation than 400 feet above the sea; but as the deposit to which they belong reaches to the height of 1,100 feet or more in the interior, they believed that an upheaval of at least that amount had taken place. The *Clypeaster altus*, L., *Spondylus gæderopus*, L., *Pectunculus pilosus*, L. sp., *Cardita calyculata*, L. sp., and several other shells, serve to identify this formation with that of the Madeiras, and *Ancillaria glandiformis*, Lam, which is not rare, and some other fossils, remind us of the faluns of Touraine.

These tuffs of the southern shores of the Grand Canary, containing the Miocene shells, appear to be of about the same age as the most ancient volcanic rocks of the island. Over the marine lavas and tuffs, trachytic and basaltic products of subaërial volcanic origin, between 4,000 and 5,000 feet in thickness, have been piled, the central parts of the Grand Canary reaching the height of about 6,000 feet above the level of the sea. A large portion of this mass is of Pliocene date, and some of the latest lavas have been poured out since the time when the valleys were already excavated to within a few feet of their present depth.

Azores.—In the island of St. Mary's, one of the Azores, marine fossil shells have long been known. They are found on the north-east coast on a small projecting promontory called Ponta do Papagaio (or Point Parrot) chiefly in a limestone about twenty feet thick, which rests upon, and is again covered by, basaltic lavas, scoriæ, and conglomerates. The pebbles in the conglomerate are cemented together by calcium carbonate.

One of the most characteristic and abundant of the species, *Cardium Hartungi*, Bronn, not known as fossil in Europe, is very common in Porto Santo and Baixo, and serves to connect the Miocene fauna of the Azores and the Madeiras. In some of the Azores, as well as in the Canary Islands, the volcanic fires are not yet extinct, as the recorded eruptions of Lanzerote, Teneriffe, Palma, St. Michael's, and others attest. The late soundings (1873) of H.M.S. 'Challenger' have shown the Azores, Canaries, Cape de Verde Islands, &c., to be merely the highest summits of a great submerged mountain ridge, comparable with the Andes of South America both in extent and altitude, as well as in the volcanic character of many of its most elevated peaks.

TERTIARY VOLCANOES IN OTHER PARTS OF THE WORLD

All over the globe we find evidence that the older parts of volcanoes still active, and many volcanoes now extinct, were in eruption during different parts of the Tertiary period.

Hindostan.—A vast volcanic area exists in the Western and Central parts of the Peninsula of Hindostan, called 'the Deccan and Malwa Trap.' It covers 200,000 square miles, and is found as numerous flows of earthy basalt, amounting to 3,000 feet in thickness. This vast deposit seems to have come from fissures upon which the volcanic cones, which were doubtless thrown up, have not been preserved, and the flows covered an old terrestrial surface of the Upper Cretaceous age.

The lava flows continued during a vast period of time (for lake-beds exist amongst them with their fossils silicified), and are older than the Nummulitic period.

The United States.—In the Western Territories of the United States the Sierra Nevada has a great thickness of auriferous gravels of Pliocene age, covered by basalt, and this is a part of the result of a grand series of eruptions from volcanoes, which continued probably into the Historic period. Such flows are vast in amount in other regions, and were one of the great phases in the development of the physical features of the continent after the upheaval of the mountain systems. The great lakes to the west of the Rocky Mountains were in existence when the outflows took place in and to the west of the mountains. The basalts form important features in Nevada, Oregon, Idaho, Utah, &c.

Besides the basaltic rocks, great masses of andesites (altered into propylites) with a few trachytes and phonolites, and many interesting rhyolites and obsidians were erupted during the Tertiary period in this part of the earth's surface. The geyser district of the Yellowstone Park, where so many traces of volcanic activity are still to be witnessed, has become very famous, and the phenomena displayed there have been carefully studied by the United-States geologists, Messrs. Hague and Iddings.

Australia. — Vast volcanic flows occurred in Australia during the Tertiary ages, and those of Queensland and of Victoria are of great importance, both geologically and economically. Marine and freshwater deposits, the ages of which can be determined by their fossils, are covered by, or rest upon, great thicknesses of dolerites. There are two series of outflows, an upper and a lower, and the

auriferous deposits are covered by the upper and rest on the lower. Where the upper or Pliocene basalt is absent or has been denuded, the sedimentary strata at once afford the gold-seeker his clue; for if they contain marine fossils, they are older than the age when the denudation of exposed auriferous quartz-reefs permitted the accumulation of auriferous deposits. The marine strata are of Miocene age, and the basalt covering them underlies the auriferous freshwater deposits, the results of the denudation of higher ground than that covered by the older and marine series. In the northern part of Queensland, north of lat. 21°, the upper volcanic series consists of well-defined craters and great lava flows, which are older than the Pleistocene marsupials (p. 241), the foreshadowers of the existing fauna. In Queensland, these Pliocene flows cap a 'desert sandstone,' and in Victoria, gravels, conglomerates, cement-beds, and other Pliocene auriferous deposits. The Victorian Pliocene volcanic flow is at a considerable altitude, and has been much denuded.

Beneath the Pliocene volcanic rocks an older series occurs, both in Victoria and Queensland, which has been referred to the Miocene. In the case of these older lava-flows, all traces of the cones and craters from which they were emitted would seem to have disappeared, probably through denudation.

CHAPTER XXXIV

VOLCANIC ROCKS OF THE MESOZOIC, PALÆOZOIC, AND ARCHÆAN ERAS

Absence of evidence of volcanic action in Cretaceous and Jurassic times in the British Isles and Western Europe—Triassic Volcanoes of Devonshire—Permian Volcanoes of Scotland—Volcanoes of the Carboniferous Period—Buried trees of Arran—Volcanoes of the Old Red Sandstone and Devonian Period—Volcanoes of the Silurian, Ordovician, and Cambrian Periods—Pre-Cambrian Volcanoes—Pre-Tertiary Volcanoes of other parts of the globe—Cretaceous and Jurassic volcanic Rocks of Greece—Newer and older Palæozoic Volcanoes of Central Europe—Pre-Cambrian volcanic Rocks of Canada.

In the British Islands we have no volcanic rocks of either Cretaceous or Jurassic age, and the same is true of Western Europe generally. It is this circumstance which led continental geologists to regard the Tertiary volcanic rocks as having a totally different character and origin from the igneous products of the older geological periods; it was found impossible, in many cases, to show a complete sequence and transition from the older to the newer volcanic rock-masses, and the former were supposed to have been extruded under the sea from great fissures in the earth's crust, being called 'trap-rocks' (from the Swedish *trappa*, a stair).

Volcanic Rocks of the Triassic Period.—The youngest pre-Tertiary volcanic rocks which occur in the British Islands

are probably those found in the south-west of England, which were described by Sir Henry de la Beche.

In the southern part of Devonshire volcanic rocks are associated with New Red Sandstone, and, according to De la Beche, have not been intruded subsequently into the sandstone, but were produced by contemporaneous volcanic action. Some beds of grit, mingled with ordinary red marl, resemble ashes ejected from a crater; and in the stratified conglomerates occurring near Tiverton, are many angular fragments of porphyrite or altered andesite, some of them one or two tons in weight, intermingled with fragments of other rocks. These angular fragments were probably thrown out from volcanic vents, and fell upon sedimentary matter then in the course of deposition.

There still appears to be some doubt, however, whether the red sandstones with which these volcanic rocks are associated may not be of Permian rather than of Triassic age, and that they were so was the view maintained by Murchison.

Volcanic Rocks of the Permian Period.—The researches of the officers of the Geological Survey in Scotland have led to their mapping a considerable number of small and scattered volcanic masses, consisting of small intrusive masses, and sometimes of lava-sheets with interbedded tuffs. The lavas are generally porphyrites and melaphyres (altered andesites and basalts), but the evidence on which a Permian age has been assigned to them cannot be regarded in most cases as altogether satisfactory. The volcanoes, which were in nearly all cases of small size, must be regarded as examples of sporadic outbursts similar to the 'puys' of Auvergne, and like them marking the decline of volcanic activity in the districts where they occurred. Volcanic rocks which have been referred to the Permian period by the officers of the Geological Survey occur in Ayrshire, in Nithsdale, in Dumfriesshire, and away through Central Scotland into Fifeshire.

Volcanic Rocks of the Carboniferous Period.—Two extensive developments of volcanic rocks occur in the Carboniferous basin of the Forth in Scotland. One of these is well exhibited along the shores of Fifeshire, where the igneous masses consist of basalt, sometimes with olivine, and of dolerites. These appear to have been erupted while the sedimentary strata were in a horizontal position, and to have suffered the same dislocations which those strata have subsequently undergone. In the associated volcanic tuffs of this age are found not only fragments of limestone, shale, flinty slate, and sandstone, but also pieces of coal. Other volcanic rocks connected with the Car-

boniferous formation may be traced along the south margin of Stratheden, and constitute a ridge parallel with the Ochils, extending from Stirling to near St. Andrews. These consist almost exclusively of dolerite, becoming, in a few instances, earthy and amygdaloidal. They are either interbedded with, or intruded among, the sandstone, shale, limestone, and ironstone of the Lower Carboniferous.

The Cement-stone group (p. 370) accumulated, writes Sir A. Geikie, in a region of shallow lagoons, islets, and coal-growths, which was dotted over with innumerable active volcanic vents. The eruptions continued into the time of the Carboniferous limestone, but ceased before the deposition of the Millstone grit. Close-grained basalts and dolerites were formed with felsites, porphyrites, and tuffs.

Beneath this group there are evidences of vast volcanic flows, some sheets being 1,500 feet thick. The most persistent zone of volcanic rocks in the Scottish Carboniferous system is that which succeeds the lower part of the Calciferous Sandstones. Composed of successive sheets of porphyrites and tuffs, it sweeps in long isolated ranges of hills from Arran and Bute on the west to the mouth of the estuary of the Forth on the east, and from the Campsie Fells on the north to the heights of Ayrshire, and still further south to Berwickshire, Liddesdale, and the English border.

Erect trees buried in volcanic ash at Arran.—An interesting discovery was made in 1867 by Mr. E. A. Wünsch in Carboniferous or Permian strata of the north-eastern part of the island of Arran. In the sea-cliff, about five miles north of Corrie, near the village of Laggan, strata of volcanic ash occur, forming a solid rock cemented by calcium carbonate and enveloping trunks of trees, determined by Mr. Binney to belong to the genera *Sigillaria* and *Lepidodendron*. The trees with their roots occur in two distinct strata of volcanic tuff, parallel to each other, and inclined at an angle of about 40°, having between them beds of shale and coaly matter seven feet thick. It is evident that the trees were overwhelmed by showers of ashes from some neighbouring volcanic vent, as Pompeii was buried by matter ejected from Vesuvius. The trunks, several of them from three to five feet in circumference, remained with their Stigmarian roots spreading through the stratum below, which had served as a soil.

Arthur's Seat, Edinburgh, is the relic of a volcanic cone, and commencing as a fissure in the Calciferous Sandstone age, gave forth andesitic and basaltic lavas, of which much was forced amongst the surrounding strata, to form the Salisbury

Crags and other intrusive sheets at the base of the hill. The eruption probably took place in shallow water, and after a while elevation occurred and agglomerates collected, forming the higher part of the mass. The volcanic relics have participated in the general movements of the area since the Carboniferous age, and have since suffered great denudation.

Evidences of similar sporadic or 'puy-like' eruptions during the Carboniferous period are found scattered all over the Central Valley of Scotland. The rocks of which these old Carboniferous volcanoes were composed have been described by Mr. Allport and Sir A. Geikie. They consist for the most part of andesites and basalt, but some trachytes and an occasional phonolite may also be found among them.

Great sheets of melaphyre, porphyrite, and tuff are found in the Carboniferous limestone of Limerick, and to the north in Ireland. In Derbyshire, sheets of contemporaneous basaltic lava called 'toadstone' occur in the limestone, and flows of the same age have been found in the Isle of Man.

Volcanic Rocks of the Old Red Sandstone Period.—By referring to the section explanatory of the structure of Forfarshire, already given (p. 80), the reader will perceive that beds of conglomerate, No. 3, occur in the middle of the Old Red Sandstone system, 1, 2, 3, 4. The pebbles in these conglomerates are sometimes composed of gneiss and quartzose rocks, sometimes exclusively of different varieties of lava, which last, although purposely omitted in the section referred to, is often found either intruding itself in amorphous masses and dykes into the old fossiliferous tilestones, No. 4, or alternating with them in conformable beds. All the different divisions of the red sandstone, 1, 2, 3, 4, are occasionally intersected by dykes, but they are very rare in Nos. 1 and 2, the upper members of the group consisting of red shale and red sandstone. These phenomena, which occur at the foot of the Grampians, are repeated in the Sidlaw Hills; and it appears that in this part of Scotland volcanic eruptions were most frequent in the earlier part of the Old Red Sandstone period. These lavas belong for the most part to the class of porphyrites, their structure is often found to be amygdaloidal, the kernels being sometimes calcareous, but often siliceous, and forming beautiful agates. In a more or less decomposed condition these felspathic lavas are known under the name of claystones. With them occur beds of stratified tuff and conglomerate. Some of these rocks look as if they had flowed as lavas over the bottom of the sea, and enveloped quartz pebbles which were lying there, so as to form conglomerates with a base of igneous rock, as is seen in Lumley

Den in the Sidlaw Hills. On either side of the axis of this chain of hills (see section, p. 80) the beds of massive lava, and the tuffs composed of volcanic ashes, dip regularly to the south-east, or north-west, conformably with the shales and sandstones.

The geological structure of the Pentland Hills, near Edinburgh, shows that igneous rocks were there formed during the Devonian or 'Old Red' period. These hills rise 1,900 feet above the sea, and consist of conglomerates and sandstones of Devonian age, resting on the inclined edges of grits and slates of Upper Silurian date. The contemporaneous volcanic rocks intercalated in this Lower Old Red Sandstone consist of felspathic lavas or felstones, with agglomerates and ashy beds.

Volcanic rocks are found associated with the strata of the Lower, Middle, and Upper Old Red Sandstone, and occur in the Cheviot Hills (where beautiful glassy enstatite-andesites are found), in the Central Valley of Scotland, and in the Orkney and Shetland Islands. Similar rocks are found associated with Old Red Sandstone strata in the Killarney district in Ireland, and with the Marine Devonian beds of the South-West of England. The lavas of this period comprise andesites and basalts, often much altered, and more rarely the acid rhyolites.

Silurian and Ordovician volcanic rocks.—The Upper Silurian series of the West of Ireland shows successive sheets of lava and tuffs forming conspicuous bands amongst the stratified rocks. The volcanic series of the Lake-district of the North-West of England is of vast thickness, and intervened between the Skiddaw slates and the Coniston limestone and shale. It occupied much of the Bala age, and all that of the Llandeilo, and part of the Arenig epoch of Wales.

The Snowdonian hills, in Caernarvonshire, consist, in great part, of volcanic tuffs, the oldest of which are interstratified with the Bala and Llandeilo beds. There are contemporaneous felsitic lavas of this era, which altered the slates on which they repose, having doubtless been poured out over them in a melted state, whereas the slates which overlie them, having been deposited after the lava had cooled and consolidated, have entirely escaped alteration. But there are 'greenstones' associated with the same formation, which, although they are often conformable to the slates, are in reality intrusive rocks. They alter the stratified deposits both above and below them.

Volcanic action occurred largely during the formation of the Arenig strata, and felsitic or rhyolitic lavas were erupted, and interstratified with fossiliferous deposits. Tuffs added to the bulk of the whole. Cader Idris, the Arans, the Arenigs, and

other mountains are thus built up. Similar volcanic rocks of Ordovician age occur in Scotland and Ireland.

Cambrian volcanic rocks.—On the western flank of the Malverns in Herefordshire, some black shales belonging to the Upper Lingula Flags are interstratified with thin sheets of vesicular lava that were probably erupted beneath the sea contemporaneously with the deposition of the muddy sediment. The shales lying beneath the volcanic rock are white, as if calcined by the molten lava, while those lying above have retained their normal black colour. In speaking of this ancient volcanic outburst, the late Professor Philipps said: 'One might mistake the ferruginous and cellular stone for the subaërial reliquiæ of a volcano in Auvergne,' a district where the erupted volcanic matter is clearly contemporaneous with the associated sedimentary deposits.

Pre-Cambrian volcanic rocks.—Beneath the lowest fossiliferous Cambrian rocks, and the basal conglomerate of the formation in Wales and elsewhere, is a vast volcanic series, the agglomerates, tuffs, and flows of which have been altered to a certain extent by metamorphic action. These Pebidian rocks have already been noticed (p. 434). Beneath the hälleflintas is the great group known as Dimetian series, in which metamorphic and granitoid masses with acid volcanic rocks are found. The Lewisian (or Fundamental) gneiss of Scotland is largely made up of rocks which are evidently metamorphosed igneous masses, some of them having apparently been extruded in the form of lavas and tuffs during the ancient periods when these rocks were formed.

PRE-TERTIARY VOLCANIC ROCKS IN OTHER PARTS OF THE WORLD

The absence of Mesozoic volcanic rocks, which is so marked a feature in the British Islands and throughout Western Europe, is not noticed in other parts of the globe. Even in the eastern part of our own Continent important volcanic rocks are found intercalated with Cretaceous and Jurassic strata.

Cretaceous Period. — M. Virlet has shown in his account of the geology of the Morea, that certain volcanic rocks in Greece are of Cretaceous date; as those, for example, which alternate conformably with Cretaceous limestone and greensand between Kastri and Damala in the Morea. They consist in great part of diallage rocks and serpentine, and of an amygdaloid with calcareous kernels, and a base of serpentine. In certain parts of the Morea, the age of these volcanic rocks is established by the following proofs: first, the lithographic limestones of the Cretaceous era are cut through by volcanic rocks, and then a conglomerate occurs, at Nauplia and other places, containing in its calcareous cement many well-known fossils of the chalk and greensand,

together with pebbles formed of rolled pieces of the same serpentinous rocks as appear in the dykes above alluded to.

Period of Oolite and Lias. Although the green and serpentinous volcanic rocks of the Morea belong chiefly to the Cretaceous era, as before mentioned, yet it seems that some eruptions of similar rocks began during the Oolitic period; and it is probable that a large part of the volcanic masses called ophiolites in the Apennines, and associated with the limestone of that chain, are of corresponding age. Important masses of volcanic rock in the Rajmahal district of Hindostan are of Jurassic age.

Volcanic rocks of Mesozoic and Palæozoic Age.—In Central Europe we find vast thicknesses of lavas and tuffs of acid, intermediate, and basic composition alternating with sediments of Triassic, Permian, Carboniferous, Devonian, Silurian, Ordovician, and Cambrian age, and similar rocks are found in Southern Europe belonging to various portions of the Newer and Older Palæozoic as well as to the Trias. The periods of volcanic eruption in our own islands in the Triassic and Permian, the Devonian, Ordovician, and Cambrian were equally periods of great igneous activity all over Western Europe. The products of volcanic activity in these several periods maintain a remarkable uniformity of character over tolerably wide districts, and it is thus possible to define even in these areas the boundaries of great 'petrographical provinces.'

Laurentian volcanic rocks. The Laurentian rocks in Canada, especially in Ottawa and Argenteuil, are among the oldest intrusive masses yet known. They form a set of dykes of a fine-grained dolerite, composed of felspar and pyroxene, with occasional scales of mica and grains of pyrites. Their width varies from a few feet to a hundred yards, and they have a columnar structure, the columns being truly at right angles to the sides of the dykes. Some of the dykes send off branches. These dolerites are cut through by intrusive syenite, and this syenite, in its turn, is again cut and penetrated by porphyritic felsite. All these old volcanic rocks appear to be of Laurentian date, as the Cambrian and Huronian rocks rest unconformably upon them. Whether some of the various conformable crystalline rocks of the Laurentian series, such as the coarse-grained granitoid and porphyritic varieties of gneiss, exhibiting scarcely any signs of foliation, and some of the serpentines, may not also be of volcanic origin, is a point very difficult to determine in a region which has undergone such extreme metamorphic action.

In his addresses to the Geological Society for 1891 and 1892, Sir Archibald Geikie has given an admirable summary of the work done by the Geological Survey, so far as it has gone, in determining the age of the various masses of volcanic rock met with in association with the strata of the British Islands.

PART IV

PLUTONIC ROCKS

CHAPTER XXXV

PLUTONIC ROCKS, THEIR NATURE AND COMPOSITION

Analogy of the Plutonic Rocks with those of Volcanic origin—Proofs of the deep-seated origin of Plutonic Rocks—Chemical composition of the different classes of Plutonic Rocks—Changes which they undergo—Liquid cavities in the crystals of Plutonic Rocks—Order in which the several minerals crystallise in Plutonic Rocks—Granite and its varieties—Syenites, &c.—Diorites, &c.—Nepheline Syenites and Theralites—Gabbro and its varieties—Ultra-acid Rocks—Ultra-basic Rocks—Peridotites—Pyroxenites—Amphibolites—Relations of the Ultra-basic Rocks to Meteorites.

THE plutonic rocks may be treated of next in order, as they are most nearly allied to the volcanic class already considered. In the first chapter we have described these plutonic rocks as a division of the crystalline or hypogene formations, and have stated that they differ from the volcanic rocks, not only by their more crystalline texture, but also by the absence of tuffs and breccias, which are the products of eruptions at the earth's surface, whether thrown up into the air or beneath the sea. They differ also by the absence of pores or cellular cavities to which the expansion of the entangled gases gives rise in ordinary lavas.

From these and other peculiarities, it has been inferred that the granites have been formed at considerable depths in the earth, and have cooled and crystallised slowly, under great pressure, where the occluded gases could not expand. The volcanic rocks, on the contrary, although they also have risen up from below, have cooled from a melted state more rapidly—upon or near the surface. From this hypothesis of the great depth at which the granites originated has been derived the name of 'Plutonic rocks.'

The heat which in every active volcano extends downwards to indefinite depths, must produce, simultaneously, very different effects near the surface and far below it; and we cannot suppose that rocks resulting from the crystallising of fused matter under a pressure of several thousand feet, much less several miles, of the earth's crust, can exactly resemble those formed at or near the surface. Hence the production at great depths of a class of rocks analogous to the volcanic, and yet differing in many particulars, might have been predicted, even had we no plutonic formations to account for.

It has, however, been objected, that if the granitic and volcanic rocks were simply different parts of one great series, we ought, in mountain chains, to find volcanic dykes passing upwards into lava and downwards into granite. But we may answer that our vertical sections are usually of small extent; and if we find in certain places a transition from solid to porous lava, and in others a passage from granitic rocks to solid lava, it is as much as we could expect from this kind of evidence.

The plutonic formations agree with the volcanic in exhibiting veins or ramifications proceeding from central masses into the adjoining rocks, and causing alterations in these last, which will be presently described. They also resemble volcanic masses in containing no organic remains; but they differ in being more uniform in texture, whole mountain masses of indefinite extent appearing to have originated under conditions almost precisely similar.

The most striking analogies between the Plutonic and the Volcanic rocks are seen, however, when we study their chemical composition and their mineralogical constitution. Every variety of lava—acid, intermediate and basic—has its exact counterpart in the series of plutonic rocks; it is only in its *structure* that a lava differs from its plutonic representative. While the lavas are sometimes wholly glassy in structure, and in almost all cases crypto-crystalline or micro-crystalline in their base or ground-mass, the plutonic rocks usually exhibit a more perfectly crystalline structure and often pass into masses that consist entirely of crystals of different minerals without any intervening base or ground-mass; in such cases we speak of the rock as being 'holocrystalline.'

As was suggested by Jukes, it is probable that if we could trace a mass of pumice downwards to greater and greater depths in the earth's crust, we should find the pumice losing its porous character, and becoming solid glass (or obsidian); the glassy obsidian by the development in it of crystallites and microlites would gradually acquire more and more stony

characters (rhyolite and quartz-felsite); and finally, as the crystals increased in size and perfection of development, the rock would assume the perfectly holocrystalline character (micropegmatite and granite). Similar changes could doubtless be traced in each variety of intermediate and basic lavas as it was followed to depths where it must have consolidated at a slower rate and under greater pressure.

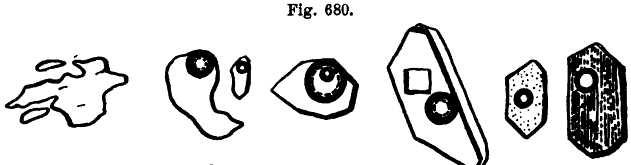
In each series, the lavas overlap their plutonic representatives. The central portions of massive lava-streams are often more highly crystalline than the materials of narrow plutonic dykes or veins. Occasionally, indeed, truly plutonic rocks, in small masses, may consolidate as a glass. While every known lava has its plutonic counterpart, there are a few deep-seated rocks, as we shall see hereafter, which seem to have no representatives among those erupted at the surface. The rocks of these peculiar types, which have only been found in plutonic dykes, constitute the class of 'dyke-rocks.' In the deeper parts of volcanic masses which have been exposed to our view by denudation, we find rocks which we may with equal propriety speak of as 'plutonic' or 'volcanic.'

Many of the plutonic rocks, like their volcanic analogues, are found to have undergone great chemical, mineralogical, and structural alterations, so that materials are produced differing very greatly indeed from the original rocks. As the result of such alteration, glassy materials become crystalline (secondary devitrification); minerals undergo metamorphoses, without alteration of chemical composition (paramorphism), or with such change (pseudomorphism); and in some cases the whole mass may become completely recrystallised with the formation of entirely new minerals. The older a rock, the more likely is it to have undergone such changes, and this circumstance led the older geologists to suppose that fundamental differences existed between the rocks of the earlier geological periods and those which have been formed in Tertiary and recent times. But the more carefully the most ancient igneous rocks are studied, the more clearly does it appear that the difference between the igneous products of the older geological periods and those of the present day are not essential but accidental—being the result of mechanical and chemical changes which they have undergone since their first consolidation. There is no ground whatever for believing that the rocks formed during the earlier periods of the earth's history differ either in chemical or mineralogical characters from those which are being consolidated within the earth's crust at the present day.

There is one respect in which the minerals of deep-seated or

plutonic rocks strikingly differ from those of the lavas formed at the earth's surface. The minerals of lavas contain cavities or empty spaces filled with gas (gas-enclosures); or with vitreous materials (glass-enclosures); or with the devitrified products of glass (stone-enclosures). The minerals of deep-seated or plutonic rocks, however, frequently contain in their cavities liquids (often with movable bubbles), and the liquids sometimes have floating about in them crystals showing that they are supersaturated solutions (see fig. 680). Sometimes crystals are found containing two different kinds of liquids at the same time. By determining the coefficient of expansion of the liquids and their critical points, and by submitting them to spectral or chemical analysis, it has been proved that they are sometimes liquid carbon dioxide (it may be mixed with other gases liquefied by pressure), at other times supersaturated aqueous solutions

Fig. 680.



a. b. c. d. e. f.

Cavities seen in the crystals of rocks.

a. Gas-cavity of irregular form. *b.* Liquid-cavities with bubbles (these cavities are irregular in form). *c.* Cavity bounded by crystalline planes of the mineral (quartz) in which it is enclosed, and containing two liquids with a bubble. Cavities thus bounded by crystalline planes are called 'negative crystals.' *d.* Similar cavity with liquid and bubble. The liquid contains a cubic crystal. *e.* Glass-cavity. *f.* Stone-cavity (both of these are negative crystals). *b, c, d* are found in minerals of plutonic rocks; *a, e, f* in minerals of lavas.

of the alkaline chlorides and sulphates. The presence of these 'liquid-enclosures' in the minerals of plutonic rocks affords striking evidence of the enormous pressures under which these rocks must have consolidated.

Two methods have been suggested whereby we may possibly be able to determine the actual temperature and pressure, and hence the depth in the earth's crust, at which a crystalline rock must have been formed. Sorby pointed out that, by measuring the relative size of the cavity and the gas-bubble in a liquid-enclosure, physicists may arrive at a definite conclusion concerning the exact conditions of crystallisation. Renard, on the other hand, would seek for the data required, by measuring the bulk of the crystals floating in the liquid of a cavity and comparing this with the volume of the supersaturated solution in which they are suspended. But our knowledge of the behaviour

of liquids and solutions at excessively high pressures and temperatures is insufficient to make calculations based on either kind of data of much practical value to geologists.

The cavities found in the crystals of plutonic rocks are sometimes so minute and numerous that many millions of them must exist in every cubic inch of the rock. In form, these cavities are very varied; sometimes they are most irregular and exhibit fine ramifications that communicate with one another; in other cases they present the crystal-faces of the mineral in which they are enclosed—forming what mineralogists know as *negative* crystals (see fig. 680, c, d, e, f).

The holocrystalline or granitic forms of rocks corresponding to the chief types of lavas are named as follows:—

Lava	Rhyolite	Holocrystalline	form	Granite.
,,	Trachyte	,,	,,	Syenite
,,	Phonolite	,,	,,	Elæolite-syenite
,,	Andesite	,,	,,	Diorite
,,	Tephrite	,,	,,	Theralite
,,	Basalt	,,	,,	Gabbro

The commonest plutonic rocks, Granite, Diorite, and Gabbro, are those which correspond to the most abundant lavas Rhyolite, Andesite, and Basalt.

In addition to the holocrystalline forms of plutonic rocks we find hypocrystalline or hemicrystalline varieties in which a less perfectly crystalline ground-mass is present. Many of these rocks, which are intermediate in structure between the 'granitic' and the lava-like or 'trachytic' forms, have received distinctive names from petrologists. Some varieties of plutonic rocks are named from the presence of a conspicuous mineral—either essential, accessory, or even secondary—while other types again are distinguished by the nature and amount of change which the minerals of the rock have undergone since its first formation.

We have seen that the basic rocks have a higher density or specific gravity than the intermediate, and the intermediate than the acid rocks. If a plutonic rock be melted and cooled rapidly, it forms a glassy mass with a much lower specific gravity than the crystalline rock from which it was produced. The lavas have always a lower specific gravity than their plutonic and more highly crystalline counterparts. Hence the determination of the specific gravity of an igneous rock with an inspection of its degree of crystallisation may enable us to draw a safe conclusion as to its chemical composition.

By examining a crystalline rock, especially in thin sections

under the microscope, we may determine the order in which the several minerals have crystallised out in a magma. Most rocks exhibit minerals belonging to different 'periods of consolidation,' to use the term employed by French petrographers. In igneous rocks generally the order in which the several minerals have separated is that of 'decreasing basicity,' as it has been defined by Rosenbusch.

Firstly.—Accessory minerals like apatite, zircon, sphene, garnet, &c.

Secondly.—Oxides of iron and titanium—magnetite, rutile, and titano-ferrite.

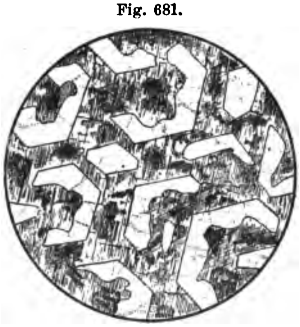
Thirdly.—The ferro-magnesian silicates—olivine, pyroxenes, amphiboles, and biotites.

Fourthly.—The alumino-alkaline silicates. The felspars in the following order: anorthite, labradorite, andesine, oligoclase, albite, orthoclase and anorthoclase, and the felspathoids.

Fifthly.—Quartz.

But in certain cases this order appears to be subject to some modification. Acid rocks sometimes show the quartz and felspar to have crystallised almost simultaneously, giving rise to the graphic or pegmatitic structure (see fig. 681), which when exhibited on a microscopic scale is known as micrographic or micropegmatitic structure. In basic rocks the augite has sometimes crystallised after the felspars, and the basic mineral is seen to enclose lath-shaped crystals of the more acid one; this gives rise to the structure called by the French petrographers 'ophitic,' and by the Germans 'diabasic.' In some plutonic rocks the crystals form radial and globular aggregates like the spherulites of the lavas, and rocks with this peculiarity, such as the well-known corsite, are said to exhibit an *orbicular* structure.

Fig. 681.



Graphic granite. Portsoy. The clear colourless crystals are quartz, the clouded ones orthoclase felspar, the former being moulded on the latter.

Acid Plutonic Rocks. Granite and its Varieties.—The granites are holocrystalline aggregates of felspar (in which orthoclastic varieties always predominate over plagioclastic) with quartz and mica—the latter mineral being sometimes replaced by hornblende and, more rarely, by a pyroxene. The orthoclastic felspar is usually allotriomorphic (that is, not bounded by its proper crystalline planes),

except when it occurs as phenocrysts or porphyritic constituents. It is often red or pink in colour, and more rarely green; it sometimes exhibits the microcline and perthite structures. The plagioclastic felspar, usually white grey or greenish in colour, appears to be oligoclase or allied to that species. The micas are sometimes black (lepidomelane) and sometimes white, and when the two varieties occur together, the rock is spoken of as granite with two micas. The white mica in granites is sometimes muscovite (muscovite-granites), but sometimes a colourless biotite. The quartz is almost always allotriomophic; it is usually colourless, but sometimes milky, while in rare cases it assumes a blue or smoky tint. In the drusy cavities of granites, the crystals of the constituent minerals are found assuming their proper form (or becoming idiomorphic). The typical granites often contain two micas, one colourless and the other deeply coloured (see fig. 683).

Gustav Rose proposed to call the more basic granites, with a large proportion of plagioclase, by the name of *granitite*. Rosenbusch applies the same name to rocks in which biotite-mica is present in considerable quantities. Hornblende- or Amphibole-granite (or granitite) is also usually a somewhat basic granite. Pyroxene-granites contain a colourless or pale green augite, or a pale-coloured and, rarely, a more ferriferous enstatite (hypersthene); of the latter class is the interesting Charnockite or hypersthene-granite of India, described by Mr. Holland.

Special accessory minerals, such as sphene, tourmaline, garnet, cordierite, pyrite, sillimanite, andalusite, &c., are present in many granites in considerable quantities; and varieties of granite are named after these constituent minerals when they are present in sufficient quantity to give a distinctive character to the rock.

Fig. 682.

Porphyritic granite. Cornwall.

Granites differ greatly in the degree of coarseness or fineness of grain. The very coarse-grained granites usually occur as veins in finer-grained varieties, and are known as *pegmatites*; but this term is often applied by French authors to graphic granites. Granites are often rendered porphyritic by large idiomorphic crystals of orthoclase felspar (see fig. 682).

Granites sometimes show an incipient foliated structure (*gneiss-granites*); at other times they are *orbicular* in structure, and not

unfrequently contain blotches or spots of a different mineralogical constitution from the general mass.

Altered granites often contain much tourmaline (as in Luxullianite) or fluor (as in Trowlesworthite), or topaz (as in greisen). When only felspar and quartz are present, the rock is called an aplite (haplite); when the felspars are replaced by muscovite and topaz we have the typical greisens. Weathering, as well as deep-seated chemical action, may lead to the kaolinisation of the felspars and the production of the 'china-clay rock,' from which the minute scales of kaolin can be easily separated by washing.

In less perfectly crystallised forms of granite, known as granite-porphyries or micropegmatites (micropegmatitic granites), the felspar and quartz usually show the intergrowths known as micropegmatitic and pseudo-spherulitic, and they are often also miarolitic or drusy in structure (see fig. 684). Such rocks are called by Rosenbusch 'granophyres,' but this term was originally employed with

Fig. 683.

Granite with two micas from Aberdeen. The clear crystals are quartz, the clouded ones felspar, and the crystals with marked parallel cleavage mica. None of the minerals are idiomorphic, and there is nothing in the nature of a ground-mass between them.

Fig. 684.

Micropegmatitic granite ('granophyre' of Rosenbusch). Between the crystals of quartz and felspar there is seen a micropegmatitic intergrowth of orthoclase and quartz. There is a drusy cavity in the centre of the slide, and the rock is therefore said to be 'miarolitic.'

a totally different signification by Vogelsang. The micropegmatitic granites pass insensibly into the quartz-felsites ('quartz-porphyr' of German authors), in which the quartz is more or less idiomorphic and the ground-mass is more or less micro-crystalline. These latter rocks are often quite undistinguishable from the stony rhyolites—especially when the latter have undergone some secondary devitrification.

Syenite and its Varieties.—The name syenite was originally applied to a granitic rock containing hornblende—like the material quarried at Syene, in Egypt, for the famous monoliths of that country. Following German authors, however, petrographers have agreed to apply the name to granitic rocks in which quartz is absent or only occurs as an accessory constituent, while the orthoclase predominates over the plagioclase (see fig. 685). Such rocks, consisting essentially of orthoclase and hornblende, are the analogues of the trachytes among the lavas. They exhibit all the varieties of

structure found in granites. When mica (biotite) replaces the hornblende we have a mica-syenite; when augite takes the place of mica, an augite-syenite; and particular varieties are known as sphene-syenite, zircon-syenite, &c., when sphene, zircon, &c., are present as conspicuous accessory minerals. The less perfectly holocrystalline forms are known as syenite-porphyry or orthoclase-porphyry (' orthophyres ').

Diorite and its Varieties.—Diorite (greenstone of the old authors) differs from syenite and granite in having plagioclase felspar present in such quantity as to predominate over orthoclase (see fig. 686). When, as is frequently the case, quartz is present in considerable quantities, we have a quartz-diorite. The felspar is usually oligoclase, but sometimes a more basic variety. The ferro-magnesian mineral in common diorite is hornblende; when hornblende is replaced by biotite we have a mica-diorite, when by enstatite we have an ensta-

Fig. 685.

Syenite from near Dresden, Saxony, consisting of orthoclase felspar (clouded) and hornblende (the dark-coloured mineral). As accessories we have some quartz (the clear mineral) and sphene (the wedge-shaped crystal in the lower right-hand part of the section).

Fig. 686.

Diorite from near Schemnitz, Hungary. The colourless zoned crystals are plagioclase felspar. The dark-coloured crystals are hornblende. Cross sections show the characteristic cleavage of that mineral. There is a little quartz present, but not enough to make the rock a quartz-diorite.

tite-diorite. Some authors employ the term augite-diorite for a similar rock in which a monoclinic pyroxene replaces the hornblende. It must be remembered, however, that many hornblendic rocks are formed by the alteration of augitic ones, and such are distinguished by petrographers as *epidiorites*. All the peculiarities of structure found in the granites are also seen in the diorites, which pass insensibly into andesites as the granites do into rhyolites. Some of the rocks intermediate in structure between the diorites and andesites are known to petrographers as diorite-porphyries. Rosenbusch has applied Gumbel's name of *lamprophyres* to rocks of this intermediate class, some having the composition of syenite, others of diorite, and all usually occurring in dykes. To this class belong the ' mica-traps ' of English authors, the *minettes* or orthoclastic mica-traps, and the *kersantites* or plagioclastic mica-traps with the rocks which Rosenbusch calls *camptonite* (minettes with hornblende or augite) and *vogesite* (kersantites with hornblende or augite).

Nepheline Syenite and its Varieties.—Nepheline- (or elæotite) syenite contains the felspathoid nepheline (or its peculiar form elæolite) in addition to the constituents of common syenite. As has been shown by Brögger, a great number of very interesting accessory minerals often occur in these rocks. They are the plutonic representatives of the phonolites.

Theralite and its Varieties.—The name theralite has been proposed by Rosenbusch for the somewhat rare rocks which resemble the nepheline-syenites, but contain a plagioclastic instead of an orthoclastic felspar. We may regard them as nepheline-diorites.

Gabbros and their Varieties.—These are the plutonic representatives of the basalts. They are holocrystalline aggregates of plagioclastic felspar (labradorite or anorthite), augite (usually converted into diallage), and magnetite or titanoferrite. Olivine is also usually present (olivine-gabbros, see fig. 687). When the augite is

Fig. 687.

Gabbro. Coruisk, Skye. The colourless crystals are plagioclase felspar; those with a strongly marked parting the altered variety of augite, known as diallage; and the irregular grains with strong outlines and cracks and a pitted surface are olivine.

Fig. 688.

Dolerite. Portree, Skye. Lath-shaped colourless crystals of plagioclase felspar are enclosed in the dark-coloured augite ('ophitic' or 'diabasic' structure). The large scattered grains are olivine, and the small black ones magnetite or titanoferrite.

replaced by an enstatite (hypersthene) we have hyperite or norite. Altered forms of gabbro are known as hornblende-gabbro, and saussurite (or smaragdite-) gabbro. Gabbros in which the olivine is quite wanting and the felspar is anorthite are called *eucrites*; those of similar character in which the augite is wanting are called *troctolites* ('Forellenstein' or trout-stone). The gabbros exhibit all the structural varieties found in the granites, and show every gradation into basalts. The rocks intermediate in structure between gabbros and basalts are known as *dolerites* (see fig. 688), or in their altered form as *diabases*. Rocks of this class, in which the ophitic structure is very conspicuous, are called by French authors *ophites*.

While all the lavas have plutonic representatives, there appear to be some rocks of the latter class which were seldom if ever erupted at the surface as lavas.

'**Ultra-acid Rocks.**'—Veins and inclusions of rock consisting of quartz, or quartz with a little orthoclase felspar, are sometimes

found among deep-seated rock masses, though rocks of this composition never appeared at the surface as lavas.

Ultra-basic Rocks.—Other veins and intrusive masses are found composed of highly basic minerals only. Those in which Olivine is the predominant constituent are called *peridotites*, particular varieties being known as *augite-*, *hornblende-*, *or mica-picrite* (see fig. 689), *dunite* (or olivine rock), Lherzolite (olivine-enstatite-augite rock with picotite, &c.), saxonite (augite-enstatite rock), &c. Rocks which are made up of one or more species of pyroxene are called *pyroxenites*; those mainly composed of varieties of hornblende, *amphibolites*. Some ultra-basic rocks, like *Cumberlandite*, consist largely of magnetite, and others, like eclogites, contain garnets.

Fig. 689.

Picrite from near Heidelberg, consisting of olivine with hornblende, augite, and biotite, and a little felspar. The olivine is partly altered into serpentine.

Fig. 690.

Bastite-serpentine. Elba. Consisting of olivine grains more or less perfectly converted into serpentine, with altered enstatite crystals (bastite).

Rocks very rich in olivine, enstatite, augite, or hornblende are readily converted into serpentine (see fig. 690); and this altered form of the ultra-basic rocks, exhibiting many interesting varieties, is found more commonly than those rocks themselves.

The ultra-basic rocks are of great interest to geologists owing to the analogies they present with the stony meteorites (aerolites). Portions of them are sometimes brought to the earth's surface in the midst of basalts or other basic lavas; and, in the same way, masses of the alloys of iron and nickel, like those of the metallic meteorites (siderites), are sometimes carried up from the earth's interior in similar basaltic lavas, as in Greenland and New Zealand.

As the meteorites are small planets which have come within the sphere of the earth's attraction and fallen on its surface, their study is of great interest to the geologist. Their average density is about 5·5, the same as that of the earth; they contain the same chemical elements as the earth's crust but in a less highly oxidised condition, and may possibly afford us a clue in speculating as to the nature of the earth's interior.

CHAPTER XXXVI

STRUCTURE AND ORIGIN OF PLUTONIC ROCK-MASSES: THEIR RELATIONS TO ROCKS OF VOLCANIC AND SEDIMENTARY ORIGIN

Plutonic Rocks can only be exposed at the earth's surface by denudation —Latest formed Rocks of this class never seen at the surface—Relations of Plutonic masses to Volcanic extrusions—Examples in the Western Isles of Scotland and Antrim—Examples in other areas—Features exhibited by Plutonic Rock-masses—Forms produced by weathering—Veins and Dykes—Segregation Veins—Result of segregative action in Plutonic Rock-masses—Inclusions and Veins—Differentiation in Igneous Magmas and its results.

Why most Plutonic Rocks are of great Geological Antiquity.—As the plutonic rocks have acquired their highly crystalline structure in consequence of having consolidated from fused magmas with extreme slowness and under enormous pressure, it follows that they could be formed only at great depths within the earth's crust. This being the case, we cannot expect to see them exposed at the earth's surface except where such an amount of denudation has taken place as to have removed the many thousands of feet of rock under which the crystalline masses were solidified. But this work of denudation being necessarily a slow one, it is clear that the chances of our finding plutonic rocks of very recent date, geologically speaking, are but small. It is doubtless true that most of the highly crystalline igneous masses now found at the earth's surface were consolidated at such a distant period, that it has been possible for the superincumbent rock-masses, under which they were found, to be stripped away by the agency of denudation; and the further we go back in geological history the more numerous become the examples of such highly crystalline plutonic rocks exposed at the earth's surface. There is no reason for doubting, however, that, if we could penetrate many thousands of feet beneath the roots of such volcanoes as Vulcano and Vesuvius, we should find the rhyolites of the one graduating through quartz-felsites into granite, and the basalts of the other passing by easy transitions through dolerites into gabbro.

Example of the Western Isles of Scotland.—There is one district, however, where (owing perhaps to the extreme amount of denudation which has taken place in late Tertiary periods) exceptional facilities are afforded to us for studying the relations of plutonic to volcanic rock-masses. The old propylites and the granites which have been intruded into them, forming the cores of

the five great volcanoes of the Western Isles of Scotland, have been fissured in all directions, and through the fissures have come up great masses of basic lava. In the narrower fissures these masses have consolidated to form dykes of basalt, in no respect differing from the materials which flowed out to form such abundant lava-floods, deluging the whole country in all directions. In some few cases the molten rock on the sides of these dykes has been cooled so rapidly, by contact with the rocks intersected, as to consolidate in the vitreous form of tachylyte or basalt-glass. But in the larger and wider fissures we find the basaltic magma, owing to slower cooling and greater pressure, taking a more highly crystalline form, usually assuming the ophitic structure and becoming a more or less coarse dolerite. In still wider fissures the dolerite is found passing into augite-gabbros, and into typical gabbros in which the augite has been converted into diallage—which is sometimes replaced by ferriferous enstatite or hypersthene, the rock then passing into a norite. These masses of gabbro often contain much olivine; they are sometimes very coarsely crystalline, at other times granulitic, and occasionally foliated or gneissic in structure; and the fissures are in places so closely crowded together that masses of highly crystalline basic rocks are formed out of which the mountain-masses of the Cuilin Hills and Blaven have been carved by denudation. In chemical composition, and in the minerals they contain, the rocks forming the great lava-streams are identical with those occupying fissures; it is mainly in the extent to which crystallisation has gone on in them that they differ. Among the materials found in the fissures every stage of the crystallising process can be traced from the glassy tachylytes to the coarsest grained gabbro and norite, like that found around the famous Loch Coruisk.

In this case, of course, the direct connection of the individual lava streams with the dykes occupying the fissures from which they have issued, is no longer seen, owing to the great denudation to which these old volcanoes have been subjected. But in some recent volcanoes, as shown by Abich, we may actually see the lava occupying a fissure joined to and continuous with that which has flowed out as a stream at the surface (see fig. 662, p. 475).

Example in Antrim.—In the Western Isles of Scotland the cases in which acid lavas (rhyolite, &c.) of the same age as the plutonic rock (granite) have been poured out in the district are neither numerous nor well displayed. But in Antrim, as has been shown by the officers of the Irish Geological Survey, the intrusion of granitic rocks into the older basalts and other lavas was accompanied by the formation of at least one rhyolitic volcano, that of Tardree, which has been studied by Von Lasaulx, and more recently by Professor G. A. J. Cole. In this case we find perfectly glassy rocks—'the pitchstone-porphyry' of Sandy Braes—graduating into every variety of stony, and often banded and spherulitic, rhyolite. This rock in turn passes into the very coarsely crystalline type known as 'Nevadite.' On the other hand, there is found in the Mourne Mountains a true granite, like that of Arran or Skye, passing as in those districts into the micropegmatitic and drusy rock ('granophyre' of Rosenbusch), and this into various forms of quartz-felsite. There can be little doubt that the officers of the Geological Survey are right in referring to the same period and the same great mani-

festation of igneous activity the granitic rocks of the Mourne Mountains and the rhyolite rocks of Tardree. And we thus see that the intimate relations between the plutonic and volcanic rocks of acid compositition are scarcely less obvious and striking than those of the same two sets of rocks of basic composition as seen in Skye, Mull, Rum, and Ardnamurchan.

In other districts, the close relations between plutonic masses of diorite, syenite, elæolite-syenite, &c., and the volcanic andesites, trachytes, phonolites, &c., can be traced with more or less distinctness. But we have often to be content with piecing together different portions of the chain of evidence. Plutonic rocks of all classes are found graduating from perfectly vitreous types into the most highly crystalline or granitic forms of identical composition. On the other hand, true lavas that have been poured out at the surface may in the central portions of their larger masses lose all trace of scoriaceous or vitreous character and pass into crystalline varieties, undistinguishable from those of intrusive plutonic rocks of the same composition.

General Features exhibited by Plutonic Rock-masses. There are striking analogies between the general forms and relations of plutonic rock-masses of different chemical composition. Granites, syenites, diorites, gabbros, &c., all exhibit similar structural forms, and the same relations with the stratified and other rocks among which they lie. Hence what we state with respect to granite in the following pages holds almost equally true of other plutonic rock-masses, diorites, syenites, elæolite-syenites, theralites, and gabbros.

Granite often preserves a very uniform character throughout a wide range of territory, frequently forming hills of a peculiar rounded form, clad with a scanty vegetation. It occurs frequently in vast masses in the midst of mountain ranges, and the metamorphic rocks, such as gneiss and mica schist, are in contact with its flanks. It may project as an important feature in the scenery, forming

Fig. 691.

Mass of granite near the Sharp Tor, Cornwall.

continuous and grand mountains, or only be noticed as lines of bosses which are evidently continuous with intrusive veins from a main mass. While, as in Arran, granite sometimes forms craggy peaks, or, as in Skye, rounded or dome-like mountains, vast surfaces of the earth are covered by granite which does not rise into high mountains, but maintains a rolling bossy outline like the Moor of Rannoch.

The surface of the rock is for the most part in a crumbling state, with harder bosses here and there; and the hills are often surmounted by piles of stones, or Tors, like the remains of a stratified mass, as in the annexed figure, and sometimes like heaps of erratic boulders, for which they have been mistaken (see fig. 691). The exterior of these stones, originally quadrangular, acquires a rounded form by the action of air and water, for the edges and angles waste away more rapidly than the sides. Although it is the general peculiarity of granite to assume no definite shapes, it is nevertheless occasionally subdivided by fissures, so as to assume a cuboidal and even a columnar structure. Examples of these appearances may be seen near the Land's End in Cornwall. (See fig. 692.)

Fig. 692.

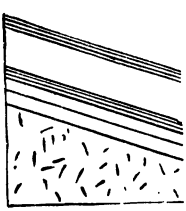
Granite having a cuboidal and rudely columnar structure. Land's End, Cornwall.

The face of the granite having disintegrated, and much of it having been carried off by wind, rain, and sometimes by streams, the highest point of the tallest tor or pinnacle represents a former level of the undenuded surface of the country, so that the present surface level on which the tor rests has been the result of the denudation of ages. Other rocks have been worn away before the granite became visible, and it has become so by a vast process of natural uncovering. In the instance of the more or less central granites of mountain chains the rock has participated in the movements which have crumpled and folded the crust of the earth, and have forced up deeply seated structures amidst great curvatures. Subsequently, enormous denudation has laid the rock bare. These remarks hold

good for the other plutonic rocks; and it must be understood that where any of them have been discovered, they present the appearances of having been forced upwards as intrusive masses or veins. The original rock underlying everything else has not been traced in position, and granitic veins are found in the lowest visible rock-masses.

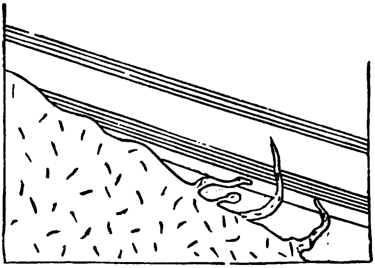
Granitic Veins.—The close analogy in the forms of certain granitic and volcanic veins and dykes has been already pointed out; and it will be found that strata penetrated by plutonic rocks have suffered changes very similar to those exhibited near the contact of volcanic dykes. Thus, in Glen Tilt, in Scotland, alternating strata of limestone and argillaceous schist come in contact with a mass of granite. The contact does not take place as might have been looked for if the granite had been formed there before the strata were deposited, in which case the section would have appeared as in fig. 693; but the union is as represented in fig. 694, the undulating outline of the granite intersecting different strata,

Fig. 693.



Section as it would appear if the strata had been deposited on the granite.

Fig. 694.



Junction of granite and argillaceous rock in Glen Tilt. (Macculloch.)

and occasionally intruding itself in tortuous veins into the beds of clay slate and limestone, from which it differs so remarkably in composition. The limestone is changed in character by the proximity of the granitic mass or its veins, and acquires a more compact texture, like that of hornstone or chert, with a splintery fracture, and it effervesces but slowly with acids.

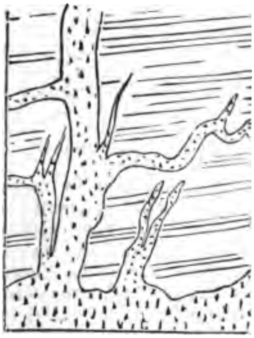
The conversion of the limestone in these and many other instances into a siliceous rock, effervescing slowly with acids, would be difficult of explanation, were it not ascertained that such limestones are always impure, containing grains of quartz, mica, or felspar disseminated through them. The elements of these minerals, when the rock has been subjected to great heat, may have been made to combine with the calcium carbonate. But besides this, siliceous matter may be introduced during the hydrothermal action which accompanied the intrusion of the igneous mass.

In the plutonic, as in the volcanic rocks, there is every gradation from a tortuous vein to the most regular form of a dyke,

such as intersect the tuffs and lavas of Vesuvius and Etna. Dykes of granite may be seen, among other places, on the southern flank of Mount Battock, one of the Grampians, the opposite walls sometimes preserving an exact parallelism for a considerable distance. As a general rule, however, granite veins in all quarters of the globe are more sinuous in their course than those of volcanic rocks. They present similar shapes at the most northern point of Scotland and the southernmost extremity of Africa, as the annexed drawings will show (figs. 695, 696).

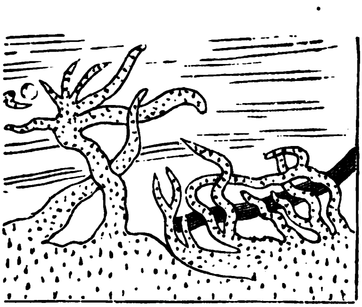
It is not uncommon for one set of granite veins to intersect another; and sometimes there are three sets, as in the environs of Heidelberg, where the granite on the banks of the river Neckar is seen to consist of three varieties, different in colour, grain, and various peculiarities of mineral composition. One of these, which is evidently the second in age, is seen to cut through an older

Fig. 695.



Granite veins traversing clay slate. Table Mountain, Cape of Good Hope (Capt. Basil Hall).

Fig. 696.



Granite veins traversing gneiss. Cape Wrath. (Macculloch.)

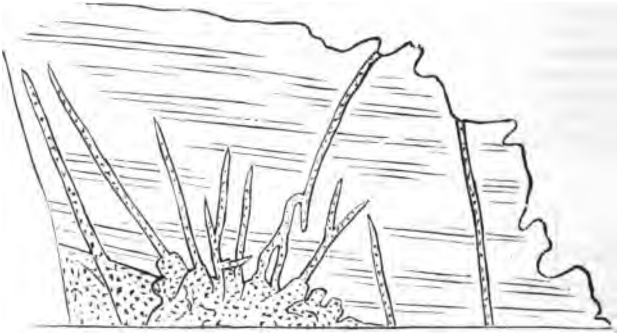
granite; and another, still newer, traverses both the second and the first. In Shetland, according to Macculloch, there are two kinds of granite. One of them, composed of hornblende, mica, felspar, and quartz, is of a dark colour, and is seen underlying gneiss. The other is a red granite, which penetrates the dark variety everywhere in veins.

Fig. 697 is a sketch of a group of granite veins in Cornwall, given by Von Oeynhausen and Von Dechen. The main body of the granite is of a porphyritic structure, with large crystals of felspar; but in the veins it is fine-grained, and without these large crystals. The general width of the veins is from 16 to 20 feet, but some are much wider.

The granites, syenites, diorites, felsites, and indeed all plutonic rocks, are frequently observed to contain metallic veins at or near their junction with stratified formations. On the other hand, similar veins which traverse stratified rocks are, as a general law,

more metalliferous near such junctions than in other positions. Hence it has been inferred that these metals may have been diffused through the molten mass, and that the contact of another rock at a different temperature, or sometimes the existence of rents in other rocks in the vicinity, may have caused the transfer of the metallic compounds to their present situation.

Fig. 697.

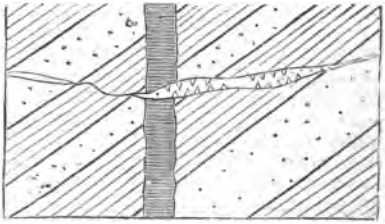


Granite veins passing through hornblende slate. Carnsilver Cove, Cornwall.

Veins of pure quartz are often found in granite, as in many stratified rocks, but they are not traceable, like veins of granite or lava, to large bodies of rock of similar composition. They appear to have been cracks, into which siliceous matter was infiltrated. Such segregation, as it is called, can sometimes clearly be shown to have taken place long subsequently to the original consolida tion of the containing rock. Thus, for example, in the gneiss of

Fig. 698.

Gneiss. Greenstone dike. Gneiss.



a, *b*. Quartz vein passing through gneiss and greenstone. Tronstadt Strand near Christiania.

Tronstadt Strand, near Drammen, in Norway, the annexed section is seen on the beach. It appears that the alternating strata of whitish granitiform gneiss and black hornblende schist were first cut through by a greenstone dyke, about 2½ feet wide; then the crack *a*, *b*, passed through all these rocks, and was filled up with

quartz. The opposite walls of the veins are in some parts incrusted with transparent crystals of quartz, the middle of the vein being filled up with common opaque white quartz.

When masses of granite approach, or are visible at, the surface of the earth, their relations to the strata and rocks on all sides, and above, are often very difficult to understand. The surrounding rocks are often greatly altered in their stratification and mineral nature.

In many localities there are great extensions of granite far below the surface, which have only become known by the coming up of veins to the surface and the alterations which have occurred in the rocks which have not yet been denuded off.

Results of Segregative Action in Plutonic Rock-masses. The tendency of the more basic minerals in rocks to crystallise before those of acid composition, and of the still fluid materials to separate from the crop of earlier-formed crystals, may give rise to a want of homogeneous character to igneous rock-masses. But in addition to this action, there can be little doubt that, in many cases, the masses of fused silicates containing water and gases tend to break up into magmas of different composition, density, and fusibility. In addition to the composite dykes formed by the injections of fissures in an older dyke with later materials of different chemical composition, there is another class of composite dykes (which has been specially studied by Professors Vogt and Lawson), in which segregative action has clearly operated upon the liquid materials after they have filled the dyke, and caused the rock occupying its centre to have a different chemical composition and mineralogical constitution from that forming its sides.

The same kind of action, as has been shown by Mr. Harker, takes place in plutonic intrusions of much greater dimensions than dykes, and has been described by that author as occurring at Carrock Fell. Most granitic and other plutonic rocks are also found to contain inclusions or irregular patches of different chemical composition from the general mass of the rock. These inclusions, as shown by the late John Arthur Phillips, belong to two distinct classes. We sometimes find fragments of schist and other rocks which have clearly been caught up in the liquid mass during its intrusion, and we can detect every gradation from fragments in which the sedimentary origin is obvious to others which have suffered such complete fusion and recrystallisation as to betray no signs of their origin. On the other hand there are inclusions which have undoubtedly been formed by segregative action going on in the consolidating magma; such 'segregative inclusions' usually consist of the same minerals as form the mass of the rock, but in different proportions; sphene and the more basic minerals, biotite and hornblende, are especially abundant in these segregative masses, which are sometimes found only half enveloping a large 'phenocryst' of the rock, while they occasionally exhibit an orbicular structure.

The older geologists also noticed the profusion of veins, often breaking up into the most minute ramifications, which traverse many plutonic masses. In some cases, like the veins of almost pure quartz, there can be little doubt that their existence must be due to the fissuring of the rock-mass and the infilling of the fissures

with materials 'leached out' from the general mass, probably before its complete consolidation. In many cases these veins betray very close analogies in chemical and mineralogical characters with the segregation inclusions of the same rock. Hence the old geologists spoke of these veins as 'contemporaneous' or 'segregation veins.' It must be remembered, however, as pointed out by Professor Sollas, that such veins often differ in no essential character from true intrusive veins, and that many of the so-called 'contemporaneous segregation veins' may really be of 'subsequent intrusive origin.'

The marked tendency of the volcanoes of a particular 'petrographical province' to exhibit a distinct order in the materials ejected at successive periods of eruption also points to a segregative action going on in the plutonic magmas which supplied the volcanoes (see p. 488). Physicists have suggested several distinct causes as leading to this differentiation in the masses of mixed silicates which constitute the igneous magmas.

CHAPTER XXXVII

PLUTONIC ROCKS BELONGING TO DIFFERENT GEOLOGICAL PERIODS

Plutonic Rocks were formed during the whole of the geological periods—Those of the most recent period seldom exposed at the surface by denudation—Test of the geological age of Plutonic rock-masses—Relative position—Intrusion and Alteration—Mineral composition—Included fragments—Tertiary Plutonic Rocks of Western Scotland—North-East Ireland—Elba, &c.—Difficulty of determining the age of Plutonic Rock-masses in Mountain chains—Plutonic Rocks of the Cretaceous—the Jurassic—the Carboniferous—the Ordovician—and Pre-Cambrian Periods.

On the different ages of the Plutonic Rocks.—It has been stated that the plutonic rocks were formed under greater pressure than the volcanic, and that the pressure appears to have been produced by the weight of superincumbent rocks, and by compression and crushing accompanying rock-folding and fracture. It may be that granite and similar materials underlie the deepest known strata, and that, under special conditions, they have been forced upwards and have cooled and assumed the crystalline form. Although the volcanic rocks resemble the plutonic in their general mineralogical constitution, yet it must be remembered that the rhyolites, andesites, and basalts occasionally contain minerals or associations of minerals, differing slightly from those found in granite, diorite, gabbro, and other typical plutonic rocks.

If granites and similar rocks can only be formed as the result of slow cooling and the pressure of many thousands of

feet of superincumbent material, it follows, as we have already pointed out, that only where a sufficient time has elapsed since their consolidation for the removal of these thick overlying masses by denudation, can we expect to see such highly crystalline masses exposed at the surface. Such being the case, we shall now proceed to show that inasmuch as we can never expect very important aid from fossils in determining the age of a plutonic rock, there is even greater uncertainty in arriving at just conclusions concerning the periods at which rocks of this class were formed, than in the case of rocks of volcanic origin.

Test of age by relative position.—Unaltered fossiliferous strata of every age are met with reposing immediately on plutonic rocks; as at Christiania in Norway, where the Pleistocene deposits, and at Heidelberg on the Neckar, and Mount Sorrel in Leicestershire, where the New Red Sandstone formations rest on granite. In these, and similar instances, inferiority in position is connected with the superior antiquity of granite. The crystalline rock was solid before the sedimentary beds were superimposed, and the latter usually contain rounded pebbles of the subjacent granite, but the latter never gives off veins into the rocks above.

Test by intrusion and alteration.—But when plutonic rocks send off veins into the sedimentary strata, and have altered them near the planes of contact, it is clear that, like intrusive volcanic rocks, they are newer than the strata which they have invaded and altered. Examples of the application of this test will be given in the sequel.

Test by mineral composition.—Sometimes a peculiar mineral condition distinguishes a plutonic rock, and is found prevailing throughout an extensive region; so that, having ascertained the relative age of the rock in one place, we can recognise its identity in others, and thus determine from a single section the chronological relations of large mountain masses. Having observed, for example, that the syenite of Norway, in which zircon and other peculiar minerals abound, has altered the Silurian strata wherever it is in contact, we do not hesitate to refer other masses of the same zircon-syenite in the south of Norway to a post-Silurian date. But too much reliance should not be placed on mineral character as a test of age; again and again have conclusions concerning the age of rocks, based on mineral characters only, proved to be untrustworthy.

Test by included fragments.—This criterion can only be of value in particular cases, because the fragments included in granite are often so much altered, that they cannot be referred

with certainty to the rocks whence they were derived. In the White Mountains, in North America, according to Professor Hubbard, a granite vein, traversing granite, contains fragments of slate and other rocks which must have fallen into the fissure when the fused materials of the vein were injected from below, and thus the granite is shown to be newer than those slaty and other formations from which the fragments were derived.

Tertiary Plutonic Rocks.—At many different points in the Hebrides, as in Skye, Mull, Rum, St. Kilda, &c., great masses of granite and gabbro occur in close association with the Tertiary volcanic rocks already described. Dr. Macculloch showed that the granites of Skye intersect limestone and shale which are of the age of the Lias.

Macculloch also pointed out that the granite and gabbro of the Inner Hebrides are newer than the secondary strata of these islands, and Edward Forbes afterwards showed that in Mull there are strong grounds for believing the volcanic rocks so intimately associated with the granites and gabbros to be of Tertiary age. Professor Zirkel has demonstrated that the great mountain masses of intrusive rocks, both in Mull and Skye, consist of granite and gabbro, which differ in no essential respect from the granites and gabbros belonging to the older geological periods; in Skye, these gabbros are seen in the remarkable Cuilin Hills, which are so famed for their wild and majestic scenery. And lastly, it has been shown that the great mountain groups in the Hebrides, composed of granites and gabbros, constitute the relics of five grand volcanoes which were in eruption during a great part of the Tertiary period, the earlier formed masses of granite being intruded into a series of andesitic and other lavas probably of Eocene age; while the gabbros, which break through the granites, are the consolidated reservoirs and ducts that gave rise to the great streams of basaltic lava of somewhat later age, constituting the plateaux forming so large a portion of the Hebridean Archipelago. These researches show that the Western Isles of Scotland afford a most admirable and instructive series of illustrations—not only of the intimate connection between the rocks of the volcanic and the plutonic classes respectively—but at the same time of the perfect identity, in their nature and sequence, of the phenomena of volcanic activity during former periods of the earth's history and those which are exhibited to us at the present day. There are the strongest grounds for believing that the granites of Arran and those of the Mourne Mountains in Ireland are of the same age as the granites of Skye, Mull, Rum, &c.

It has been shown by Lotti that the granites and diabases

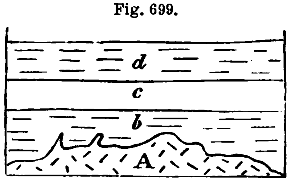
(or gabbros) of the Island of Elba are like those of our own Hebrides, of older Tertiary age.

In a former part of this volume (p. 229) the great Nummulitic formation of the Alps and Pyrenees was referred to the Eocene period, and it follows that vast movements which have raised those fossiliferous rocks from the level of the sea to the height of more than 10,000 feet above its level have taken place since the commencement of the Tertiary epoch. Here, therefore, if anywhere, we might expect to find hypogene formations of Eocene date breaking out in the central axis or most disturbed region of the loftiest chain in Europe. It was believed by the older investigators, and is still credited by some geologists, that in the Swiss Alps even the *flysch*, or upper portion of the Nummulitic series, has been occasionally invaded by plutonic rocks, and converted into crystalline schists of the hypogene class. It is stated that even the granite or gneiss of Mont Blanc itself has been in a fused or pasty state since the *flysch* was deposited at the bottom of the sea; and the question as to its age is not so much whether it be a secondary or tertiary granite or gneiss as whether it should be assigned to the Eocene or Miocene epoch.

But the student must always be on his guard against receiving statements regarding the age of granites in disturbed areas, such as those of mountain-chains. For inversions of strata in such situations are exceedingly common, and on the grandest scale.

Plutonic Rocks of the Cretaceous Period.—It will be shown in a following chapter that the Chalk and the Lias have been altered by granite in the eastern Pyrenees. Whether such granite be Cretaceous or Tertiary cannot easily be decided. Suppose *b*, *c*, *d*, fig. 699, to be three members of the Cretaceous series, the lowest of which, *b*, has been altered by the granite A, the modifying influence not having extended so far as *c*, or having but slightly affected its lowest beds. Now it can rarely be possible for the geologist to decide whether the beds *d* existed at the time of the intrusion of A, and alteration of *b* and *c*, or whether they were subsequently thrown down upon *c*. But as some Cretaceous and even Tertiary rocks have been raised to the height of more than 9,000 feet in the Pyrenees, we must not assume that plutonic formations of the same periods may not have been brought up

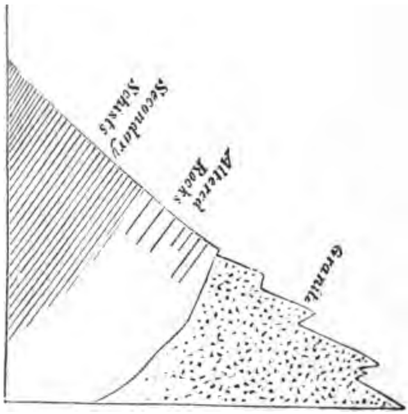
Fig. 699.



and exposed by denudation, at the height of 2,000 or 3,000 feet, on the flanks of that chain.

Plutonic Rocks of the Jurassic Period.—In the Department of the Hautes-Alpes, in France, M. Elie de Beaumont traced a black argillaceous limestone charged with Belemnites to within a few yards of a mass of granite. Here the limestone begins to put on a granular texture, but is extremely fine-grained. When nearer the junction it becomes grey, and has a saccharoid structure. In another locality, near Champoleon, a granite composed of quartz, black mica, and rose-coloured felspar, is observed partly to overlie the secondary rocks, producing an alteration which extends for about 30 feet downwards

Fig. 700.

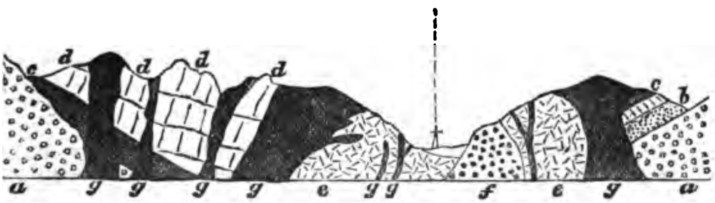


Junction of granite with Jurassic or Oolite strata in the Alps, near Champoleon.

diminishing in the beds which lie farthest from the granite (see fig. 700). In the altered mass the argillaceous beds are hardened, the limestone is saccharoid, the grits quartzose, and in the midst of them is a thin layer of an imperfect granite. It is also an important circumstance that near the point of contact both the granite and the secondary rocks become metalliferous, and contain nests and small veins of blende, galena, and iron- and copper-pyrites. The stratified rocks become harder and more crystalline, but the granite, on the contrary, softer and less perfectly crystallised near the junction. Although the granite is incumbent in the above section (fig. 700), we cannot assume that it overflowed the strata, for the disturbances of the rocks are so great in this part of the Alps that their original position is often inverted. The age, therefore, of the granite is doubtful.

Plutonic Rocks of the Triassic Period.—The great intrusive masses consisting of 'monzonite' (augite-syenite), tourmaline-granite, hypersthene-dolerite, and other rocks, so well exhibited at Predazzo in the Tyrol, are now known to be of Upper Triassic age. The general relations of these rock-masses are represented in fig. 701. Both the acid and basic

Fig. 701.



a. Botzen porphyry, of Permian age. *b, c, d.* Stratified rocks of the Lower, Middle, and Upper Trias. *e.* Monzoni syenite, traversed by veins of hypersthene-dolerite, &c. *f.* Tourmaline-granite. *g.* Hypersthene-dolerite, and other basic rocks.

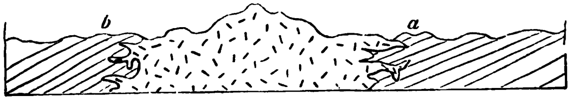
rocks show that general dip towards the centre of the mass which is so commonly seen beneath volcanoes when the underlying rock-masses are exposed by denudation. In the limestones in contact with the great intrusive rock-masses, beautifully crystallised minerals are found of precisely the same species as those ejected from Vesuvius and other recent volcanic vents.

Plutonic Rocks of the Carboniferous Period.—The granite of Dartmoor, in Devonshire, was formerly supposed to be one of the most ancient of the plutonic rocks, but is now ascertained to be posterior in date to the Culm-measures of that county, which from their position, and as containing true coal-plants and Trilobites of the *Phillipsia* group, are now known to be members of the Carboniferous series. This granite has broken through the Devonian and Carboniferous stratified formations, the successive members of the Culm-measures abutting against the granite, and becoming metamorphosed as they approach it. These strata are also penetrated by granite veins, and dykes, called 'elvans.' The granite of Cornwall is probably of the same date, and therefore as modern as the Carboniferous strata, if not newer.

Plutonic Rocks of the Ordovician Period.—It has long been thought that a very ancient granite near Christiania, in Norway, is posterior in date to the Ordovician strata of that region, although its exact position in the Palæozoic series cannot be defined. Von Buch first announced, in 1813, that it was of

newer origin than certain limestones containing Orthocerata and Trilobites. The proofs consist in the penetration of granite veins into the shale and limestone, and in the alteration of the strata, for considerable distances from their planes of contact with these veins and with the central mass from which they emanate. (See fig. 702.) When the junctions of the strata and the granite are carefully examined, it is found that the plutonic rock intrudes

Fig. 702.

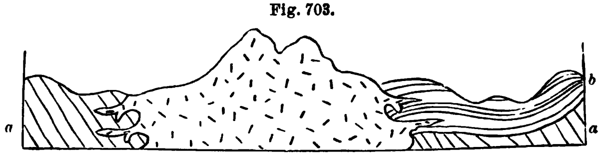


itself in veins and nowhere covers the fossiliferous strata in large overlying masses, as is so commonly the case with volcanic formations.

Now this granite, which is more modern than the Ordovician strata of Norway, also sends veins into an ancient formation of gneiss of the same country; and the relations of the plutonic rock and the gneiss, at their junction, are full of interest when we duly consider the wide difference of epoch which must have separated their origin.

The length of this interval of time is attested by the following facts:—The fossiliferous, or Silurian, beds rest unconformably upon the truncated edges of the gneiss, the inclined masses of which had been denuded before the sedimentary beds were superimposed (see fig. 703). The signs of denudation are two-

Fig. 703.



Granite sending veins into Silurian strata and gneiss. Christiania, Norway.
a. Inclined gneiss. *b.* Silurian strata.

fold: first, the surface of the gneiss is seen occasionally (on the removal of the newer beds containing organic remains) to be rounded and water-worn; secondly, pebbles of gneiss have been found in some of these Silurian strata. Between the origin, therefore, of the gneiss and the granite there intervened, first, the period when the masses of gneiss were denuded; secondly, the period of the deposition of the Silurian strata on the denuded and inclined gneiss, *a*. The granite produced after this

long interval is often so intimately blended with the gneiss at the point of junction, that all distinction is arbitrary. The whole of these rocks have been since studied with great thoroughness by Professor Brögger, who has confirmed the conclusions of his predecessors concerning their general relations.

Pre-Cambrian Plutonic Rocks.—Granite appears to have been intruded into the metamorphic rocks which are the lowest in the South Wales area—the Dimetian of Dr. Hicks; and it is possible that the veins of it did not pass beyond this lowest horizon. The Lewisian or Fundamental gneiss of Scotland contains many plutonic rocks which are certainly older, not only than the Cambrian strata, but than the Torridon Sandstone which underlies them. The investigations of the geological surveyors in Scotland lead to the conclusion, indeed, that in the northern portion of the Western Highlands, the Fundamental gneiss series consists almost wholly of plutonic rock-masses, more or less altered by the shearing movements to which they have been subjected. In addition to the hornblendic gneiss, which is the predominant rock, we find Amphibolites and Pyroxenites (Augite rocks and Hypersthene-augite rocks), Pyroxene-gneiss and granulite, and many garnet-bearing rocks. The whole of these ancient plutonic rock-masses are traversed by numerous dykes of every age, up to the Tertiary.

The Laurentian rocks of Canada have numerous veins and dykes of diabase, sometimes of great width, and they are cut across by extensive masses of syenite, with veins of reddish-brown porphyritic felsite. These intrusive rocks appear not to enter the superimposed Silurians. But it is very evident that many of the eruptive rocks found in the pre-Cambrian formations are of later age, and were erupted during the Devonian or Carboniferous age.

The intrusion of plutonic rocks into the gneisses and mica schists of Archæan and subsequent ages is exceedingly interesting, especially when fragments of the schistose rocks are found included in the plutonic masses. Very frequently there is great difficulty in determining whether a rock is a true gneiss or a granite, showing parallel arrangement of its crystals, produced by pressure during consolidation. General McMahon has shown that some of the granites of the Himalayas, which give off numerous veins into the surrounding rocks, nevertheless exhibit a marked foliated or gneissic structure.

On the following page we have given in tabular form a series of analyses of volcanic and plutonic rocks, which will illustrate the intimate relations which exist between the two great classes of igneous products.

ANALYSES OF CHIEF TYPES OF IGNEOUS ROCKS (VOLCANIC AND PLUTONIC)

	—	SILICA	ALUMINA	FERRIC OXIDE	FERROUS OXIDE	MAGNESIA	LIME	SODA	POTASH	WATER AND LOSS
ACID	APLITE (Wexford), sp. gr. 2·63	80·2	12·2	0·7	—	—	0·9	5·6	0·4	—
	GRANITE (with two Micas) (Saxony), sp. gr. 2·66	76·1	13·4	1·8	—	0·2	0·3	3·1	4·9	1·1
	GRANITITE (Odenwald), sp. gr. 2·68	69·0	14·8	2·8	0·9	1·1	3·8	2·5	4·5	1
	HORNBLENDE-GRANITITE (Odenwald), sp. gr. 2·74	65·8	18·0	4·2	0·7	2·1	5·1	1·8	2·2	1·2
	RHYOLITE (Hungary), sp. gr. 2·40	76·3	13·2	1·9	—	0·2	1·9	2·8	3·7	0·6
	RHYOLITE (Hungary), sp. gr. 2·46	69·0	17·1	—	—	—	0·7	2·3	9·7	0·9
INTERMEDIATE	'BANATITE' (Quartz Diorite) (Hungary), sp. gr. 2·72	65·7	17·1	2·8	1·8	2·6	5·2	3·9	1·0	—
	SYENITE (Saxony), sp. gr. 2·73	59·8	16·9	—	7·0	2·6	4·4	2·4	6·6	1·3
	DIORITE (Hartz), sp. gr. 2·90	54·7	15·7	2·0	6·3	5·9	7·8	2·9	3·8	1
	ELÆOLITE-SYENITE (Transylvania), sp. gr. 2·48	56·3	24·1	2·0	—	0·1	0·7	9·3	6·8	1·6
	DACITE (Quartz-Andesite) (Hungary), sp. gr. 2·50	67·2	17·0	3·5	1·2	1·5	4·5	3·7	1·6	0·9
	TRACHYTE (Bolsena), sp. gr. 2·55	59·2	18·6	—	6·1	1·1	3·0	4·9	6·7	1·1
	ANDESITE (Buffalo Peak, U.S.), sp. gr. 2·74	56·2	16·1	5·0	4·4	4·6	7·0	3·0	2·4	1·3
	PHONOLITE (Wolf Rock), sp. gr. 2·54	56·5	22·3	2·7	1·0	—	1·5	11·1	2·8	2·1
BASIC	GABBRO (Hartz), sp. gr. 3·02	49·6	16·2	1·9	12·3	5·4	9·3	1·9	0·8	3·3
	DOLERITE [Diabase] (Sweden), sp. gr. 2·98	50·2	15·0	—	16·9	5·8	10·5	2·2	1·4	0·7
	BASALT (Etna, 1865), sp. gr. 2·77	49·7	18·2	—	12·5	4·0	11·4	3·4	0·7	0·2
	LEUCITE BASALT (Bohemia), sp. gr. 2·94	40·3	11·6	21·8	—	7·6	11·1	1·4	4·2	0·8
	NEPHELINE BASALT (Germany), sp. gr. 3·04	40·5	14·9	1·0	11·2	8·0	14·6	2·9	2·	4·
	MELILITE BASALT (Germany), sp. gr. 3·04	33·9	9·9	15·6	—	16·1	15·2	2·9	—	6·4
	LIMBURGITE (Germany), sp. gr. 2·83	42·8	8·7	—	18·9	10·1	12·3	2·3	0·6	4·3
ULTRA-BASIC	LHERZOLITE (Pyrenees), sp. gr. 3·28	45·0	1·0	—	12·0	16·0	19·5	—	—	6·5
	HORNBLENDE-PICRITE (Odenwald), sp. gr. 2·82	41·4	6·6	13·9	6·3	18·4	7·2	0·2	0·9	5·6
	DUNITE (Olivine rock) (New Zealand), sp. gr. 3·3	42·8	—	—	9·4	47·4	—	—	—	0·6
	METEORITE (Chassigny, 1815)	35·8	—	—	26·7	31·8	—	—	0·7	4·9

The student will find the plutonic rocks fully described in the treatises of Rosenbusch and Tirkel, and in the English text-books of Rutley, Hatch, and Harker, already referred to. Illustrations and descriptions of the most important types of plutonic rocks in this country are published in 'Teall's British Petrography.' Valuable series of rock-analyses will be found in the works of Justus Roth.

PART V

METAMORPHIC ROCKS

CHAPTER XXXVIII

METAMORPHIC ROCKS, THEIR NATURE AND ORIGIN

Contact Metamorphism and Regional Metamorphism—Thermo-metamorphism and Hydrothermal action—Dynamo-metamorphism—Different results of Metamorphic action—Researches of Daubrée and others on Thermo-metamorphic and Hydrothermal action—Dynamo-metamorphic action and its results—Slaty cleavage—Its nature and origin—Investigations of Phillips, Sharpe, Sorby, &c.—Experimental proofs of origin of slaty cleavage—Foliation, its nature and origin—Relations between Cleavage and Foliation—Experimental researches of Daubrée, Spring, and others upon the action of pressure in producing Metamorphism.

Nature of Metamorphic Rocks.—We have now considered all the classes of rocks, except the last group, which comprises those called Metamorphic, and which result from great alteration taking place in other rocks. The term Metamorphic implies that rocks have undergone changes of chemical, mineralogical, and textural kinds, and that their internal structure and outward appearance no longer resemble those of the original rock. Such changes and alterations as are sufficient to produce a kind of metamorphism may be studied at the present day in volcanic regions, such as Iceland, or near Naples. The flowing of lava over soil, or into streams or small lakes, produces alterations in the clays and sands, which are baked by the heat and are sometimes infiltrated with siliceous solutions altering them chemically and mechanically. Similar changes occurred under analogous circumstances in past geological ages. Thus, in examining the sides of dykes and other plutonic masses, as has been already pointed out, very striking evidence is often detected of the action of heated lavas upon the clays, sandstones, or limestones with which the igneous masses have been in contact. These may be taken as examples of local, or contact, metamorphism; but on examining the rocks in the midst of

great mountain chains—slates, schists, quartzites, crystalline limestones, gneisses, &c.,—they are found in positions where originally horizontal rocks have been subjected to the weight of superincumbent rock-masses, to intense lateral pressure, to heat, and to the action of percolating gases, and of water holding various materials in solution. Such rocks, which are said to have undergone 'regional metamorphism,' are found over great tracts of country. The mountains of Cornwall, North Wales, and the Lake district, illustrate the phenomena of metamorphism, but examples of still more highly altered rocks are found in the Alps, the Scandinavian peninsula, and the North-Western Highlands of Scotland, where the results of the extreme action of this 'regional' metamorphism are fully exemplified.

There are thus two classes of metamorphic rocks, recognised by geologists; those which have been locally affected by the contact of plutonic and volcanic rock-masses, and those which have been exposed to more general action—the agencies of heat and pressure operating over wide areas, and probably at great depths from the surface. We speak of the metamorphic action in the first class of rocks as 'contact' or 'local metamorphism' and in the second as 'general' or 'regional metamorphism.'

From a study of the ultimate chemical composition of the different varieties of metamorphic rocks (see table, p. 588), it is obvious that metamorphic action has not been restricted to any one class of rocks; but that sedimentary strata, volcanic lavas and tuffs, and the materials of plutonic intrusions must alike have undergone great changes, and are now exhibited to us under very different aspects from those which they originally presented. There is probably no class of aqueous or igneous materials which is not represented among the metamorphic rocks by masses of material which—differing little if at all from them in ultimate chemical composition—have nevertheless had the whole of their constituents recombined and recrystallised.

Different kinds of Metamorphic action.—The two great agencies concerned in the production of metamorphism are heat and pressure. The effects produced by heat alone we speak of as *Thermo-metamorphism*, or, recognising the great influence exerted by the presence of water and gases in these heated masses, we often refer to it as *hydrothermal action*. The action produced on rocks by pressure we call *Dynamo-metamorphism*. Though it may be convenient to speak of these two kinds of metamorphic action as distinct from each other in their nature and their effects, it must be remembered that in most cases thermo-metamorphism and dynamo-

metamorphism co-operate in producing the characters found in metamorphic rocks.

In local or contact metamorphism, though the chief agent of change appears to have been the heat emanating from the plutonic intrusion, yet pressure must have operated in increasing the chemical action of the water and gases imprisoned in the rock undergoing alteration, or passing into it from the igneous mass with which it was in contact.

In regional metamorphism, dynamo-metamorphic action usually appears to have played a much more important part than in contact metamorphism. The researches which have been made in the distribution of underground temperature (see p. 13) rendered it highly probable, if not absolutely certain, that at a depth of 10,000 feet, or two miles from the surface of the earth, the rocks of the earth's crust must have a temperature of at least 212° F.

During the great movements to which the strata of regions now occupied by mountain chains have been subjected, subsidences of 10,000 feet and of even five times that amount have been common occurrences; and similar downward movements, as we have already shown, must have accompanied the deposition of many thick masses of sedimentary rocks, such, for example, as those of the Carboniferous system. Hence it is certain that many of these rocks have been subjected to temperature varying from that of boiling water to that of red-hot iron.

A very simple calculation serves to show that rocks, when buried at the depth of 10,000 feet from the surface, are subjected to a pressure of about 37 tons to the square inch, and that there is a progressive increase of pressure in descending to still greater depths. This pressure, produced by the weight of superincumbent rock-masses, we may speak of as *statical* pressure; its effects are seen in the liquefied gases which, as we have pointed out, are found imprisoned in the cavities of deep-seated plutonic rocks, and in the water and gases occluded in volcanic rocks, which are given off into the atmosphere when the lava issues from a vent and the pressure is relieved. The effects of these statical pressures are testified to by the condition of the minerals of all rocks which, at any period of their history, have been deep-seated. The chemical changes, which these rock-forming minerals have undergone, show that they must have been completely permeated by liquids and gases which, under the enormous pressures, were forced between the molecules of the solid crystals.

Of far greater intensity and effect, however, are the pressures

produced when great rock-masses are bent, folded, crushed, and broken across, during earth-movements such as those which are concerned in making mountain-chains. Under these conditions we find that pebbles of the hardest rocks are sometimes thrust against one another with such irresistible force as to mutually bruise and indent one another (*impressed pebbles*); rock surfaces are ground against one another so as to produce polished and striated faces (*slickensides*); and solid materials broken into angular fragments (*fault-rock*) or reduced to the finest powder (*mylonites*). The remarkable and chemical effects produced by this dynamical action we shall presently consider in greater detail.

Different ways in which Rocks have been affected by Metamorphic action.—It may be asked, then, whether all rocks which have been buried under the same thicknesses of superincumbent strata exhibit like effects of metamorphic action. A little reflection will show that there are examples of strata—like the limestones, grits, and coal-measures of the Carboniferous system—which must have been long buried under many thousands of feet of superincumbent rock, but in which, nevertheless, the changes produced have been remarkably small, and of others which, under like conditions, have undergone the most intense alteration accompanied with complete recrystallisation of their materials.

Under these circumstances, therefore, it may be desirable to inquire a little more particularly how the several agencies—heat and pressure—really operate in modifying the characters of rock-masses.

It is in rocks which have been subjected to contact-metamorphism that we can best study the direct action of *heat* in producing chemical change and recrystallisation of their materials. Rocks that have been subjected to regional metamorphism, on the other hand, best exemplify the effects of *pressure*, acting either alone or in combination with thermal or hydrothermal agencies.

Thermo-metamorphism, or Hydrothermal action.—As all rocks contain water, it must have influenced their metamorphism under heat and pressure, and its agency would be enhanced by the presence of various substances held in solution. In local metamorphism, water is introduced in excess from the intruded or overflowing volcanic rock, and also various chemical compounds in solution, with gases which act upon the surrounding strata. In regional metamorphism the excess of water does not appear to have been necessary, the original amount already contained in the rocks probably being sufficient. But hydrothermal action—that is, the influence of heated water containing dissolved solid matter, and

also gases, like hydrochloric acid and carbon dioxide, in solution —is recognised as a potent factor in metamorphism.

Thus it is known that long after volcanoes have spent their force, hot springs continue to flow out at various points in the same area. In regions also subject to violent earthquakes such springs are frequently observed issuing from rents, usually along lines of fault or displacement of the rocks. These thermal waters are most commonly charged with a variety of dissolved ingredients, and they retain a remarkable uniformity of temperature from century to century. A like uniformity is also found in the nature of the solid and gaseous substances with which they are impregnated. It is well ascertained that springs, whether hot or cold, charged with carbon dioxide, and with sulphuric, hydrochloric, boric, or hydrofluoric acids, which are often present in small quantities, are powerful causes of decomposition and chemical change in rocks through which they percolate.

The alterations which Daubrée has shown to have been produced by the alkaline waters of Plombières in the Vosges, are especially instructive. These waters have a temperature of 160° F., or an excess of 109° above the average temperature of ordinary springs in that district. They were conveyed by the Romans to baths through long conduits or aqueducts. The foundations of some of their works consisted of a bed of concrete made of lime, fragments of brick, and sandstone. Through this and other masonry the hot waters have been percolating for centuries, and have given rise to various zeolites—Apophyllite and Chabazite among others—also to Calcite, Aragonite, and Fluorspar, together with siliceous minerals, such as Opal—all found in the interspaces of the bricks and mortar or constituting part of their rearranged materials. The amount of heat brought into action in this instance in the course of 2,000 years has, no doubt, been enormous, but its intensity, or the temperature developed at any one moment, has always been inconsiderable.

From these facts and from the experiments and observations of Sénarmont, Daubrée, Delesse, Scheerer, Sorby, Sterry Hunt, and others, we are led to infer that when there are large volumes of molten matter in the earth's crust, containing water and various acids, even in excessively minute quantities, heated under pressure, these subterranean fluid masses will gradually part with their heat by the escape of steam and various gases through fissures, producing hot springs; or by the passage of the same through the substance of the overlying and injected rocks. Even the most compact rocks may be regarded, before they have been exposed to the air and dried, in the light of sponges filled with water. According to the experiments of Henry, water, under a hydrostatic pressure of 96 feet, will absorb three times as much carbon dioxide as it can under the ordinary pressure of the atmosphere. There are other gases, as well as the carbon dioxide, which water absorbs, and more rapidly in proportion to the amount of pressure. The water acts also by its affinity for various silicates, which are hydrated or decomposed. Quartz can be produced under the influence of heat by water holding alkaline silicates in solution, as in the case of the Plombières springs. The quantity of water required, according to Daubrée, to produce great transformations in the mineral structure of rocks is very small. As to the heat required, silicates may be produced in the

moist way at about incipient red heat, whereas to form the same in the dry way requires much higher temperatures.

M. Fournet, in his description of the metalliferous gneiss near Clermont, in Auvergne, states that all the minute fissures of the rock are quite saturated with free carbon dioxide; which gas rises plentifully from the soil there and in many parts of the surrounding country. The various minerals of the gneiss, with the exception of the quartz, are all softened; and new combinations of the acid with calcium, iron, and manganese are continually in progress.

The effect of subterranean gases on rocks is well illustrated in the neighbourhood of St. Calogero, in the Lipari Islands, where the horizontal strata of tuff forming cliffs 200 feet high have been discoloured in places by the jets of steam, often above the boiling point, called 'stufas,' issuing from the fissures; and similar instances are recorded by Virlet of the corrosion of rocks near Corinth, and by Daubeny of the decomposition of trachytic rocks by sulphuretted hydrogen and hydrochloric-acid gases in the Solfatara, near Naples. In all these instances it is clear that the gases must have made their way through vast thicknesses of porous or fissured rocks, and their modifying influence may spread through the crust for thousands of yards in thickness.

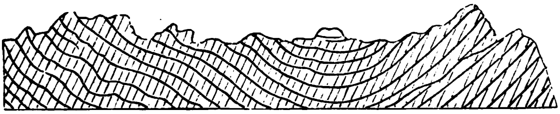
It has been urged as an argument against the metamorphic theory, that rocks have a small power of conducting heat, and it is true that when dry they differ remarkably from metals in this respect. The syenite of Norway has sometimes altered fossiliferous strata both in the direction of their dip and strike for a distance of a quarter of a mile. But in regional metamorphism the production of gneiss and mica and other schists was a slower process than local metamorphism, and the duration of the process compensated for the diminished increments of heat, pressure, and hydrothermal action. Bischoff has shown what changes may be superinduced, on black marble and other rocks, by the steam of a hot spring; and we are becoming more and more acquainted with the prominent part which water is playing in distributing the heat of the interior through mountain-masses of incumbent strata, and of introducing various chemical compounds into them, in a fluid or gaseous state.

Dynamo-metamorphic action.—While statical pressures seem to have led to the induration, or to the recrystallisation of the material of rocks, with occasional slight modifications in chemical composition, dynamical action has resulted in a rearrangement of their materials, so that the rocks often split up along planes quite distinct from those of the original bedding of the mass. When the change produced is of a mechanical character only, resulting in a rearrangement of the particles of the rock, it is called *cleavage*; but when this rearrangement is accompanied by chemical changes and recrystallisation of the rock-materials, the result is called *foliation*. The development of planes of cleavage and foliation at right angles to the directions in which pressure has been exerted is a question to which the attention of geologists and physicists has long been devoted.

Slaty cleavage.—Sedgwick, whose essay 'On the Structure of Large Mineral Masses' first cleared the way towards a better understanding of this difficult subject, called attention to the fact that joints are distinguishable from planes of slaty cleavage in this, that the rock intervening between two joints has no tendency to cleave in a direc-

tion parallel to the planes of the joints, whereas a rock is capable of indefinite subdivision in the direction of its slaty cleavage. In cases where the strata are curved, the planes of cleavage are still perfectly parallel. This has been observed in the slate rocks of part of Wales (see fig. 704), which consist of a hard greenish slate. The true bedding is there indicated by a number of parallel stripes, some of a

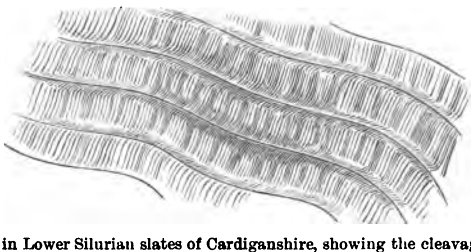
Fig. 704.



Parallel planes of cleavage intersecting curved strata. (Sedgwick.)

lighter and some of a darker colour than the general mass. Some stripes are found to be parallel to the true planes of stratification, wherever these are manifested by ripple marks, or by beds containing peculiar organic remains. Some of the contorted strata are of a coarse mechanical structure, alternating with fine-grained crystalline chloritic slates, in which case the same slaty cleavage extends through the coarser and finer beds, though it is brought out in greater perfection in proportion as the materials of the rock are fine and homogeneous. It is only when these are very coarse that the cleavage planes entirely vanish. In the Welsh hills these planes are usually inclined at a very considerable angle to the planes of the strata, the average angle being as much as from 30° to 40°. Sometimes the cleavage planes dip towards the same point of the compass as those of stratification, but often to opposite points. The cleavage, as represented in fig. 704, is generally constant over the whole of any area affected

Fig. 705.



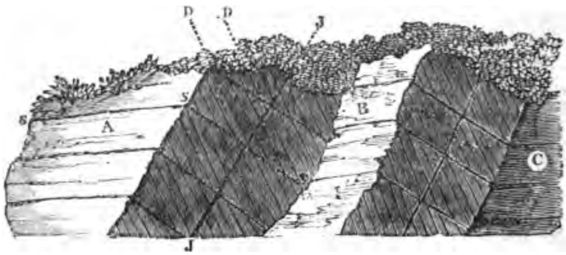
Section in Lower Silurian slates of Cardiganshire, showing the cleavage planes bent along the junction of the beds. (T. McK. Hughes.)

by one great set of disturbances, as if the same lateral pressure which caused the crumpling up of the rock along parallel, anticlinal and synclinal axes caused also the cleavage.

Professor McKenny Hughes remarks, that where a rough cleavage cuts flagstones at a considerable angle to the planes of stratification, the rock often splits into large slabs, across which the lines of bedding are frequently seen, but when the cleavage planes approach

within about 15° of stratification, the rock is apt to split along the lines of bedding. He has also called attention to the fact that subsequent movements in a cleaved rock sometimes drag and bend the cleavage planes along the junction of the beds, indicated in the

Fig. 706.



Stratification, joints, and cleavage.
(From Murchison's 'Silurian System.')

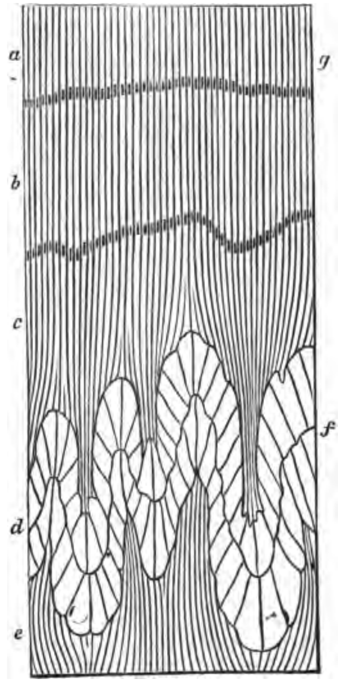
annexed section (fig. 705). The relation of cleavage planes to joints is seen in fig. 706. *The joints J J are parallel. S S are the lines of stratification; D D are lines of slaty cleavage, which intersect the rock at a considerable angle to the planes of stratification.*

Mechanical theory of cleavage.—Professor Phillips long ago remarked that in some slaty rocks, affected by cleavage, the form of the outline of fossil shells and trilobites has been much changed by distortion, which has taken place in a longitudinal, transverse, or oblique direction. This change, he adds, seems to be the result of a 'creeping movement' of the particles of the rock along the planes of cleavage, its direction being always uniform over the same tract of country, and its amount in space being sometimes measurable, and being as much as a quarter or even half an inch. Mr. D. Sharpe, following up the same line of inquiry, came to the conclusion that the present distorted forms of the shells in certain British slate rocks may be accounted for by supposing that the rocks in which they are embedded have undergone compression in a direction perpendicular to the planes of cleavage, and a corresponding extension in the direction of the dip of the cleavage. It would appear that the pressure was at right angles to the original bedding, and that it was very great.

Subsequently (in 1853) Mr. Sorby demonstrated that this mechanical theory is applicable to the slate rocks of North Wales and Devonshire, districts where the amount of change in dimensions can be tested and measured by comparing the different effects exerted by lateral pressure on alternating beds of finer and coarser materials. Thus, for example, in the accompanying figure (fig. 707) it will be seen that the sandy bed *d f*, which has offered greater resistance, has been sharply contorted, while the fine-grained strata, *a*, *b*, *c*, have remained comparatively unbent. The points *d* and *f* in the stratum *d f* must have been originally four times as far apart as they are now. They have been forced so much nearer to each other, partly by bending, and partly by becoming elongated in

the direction of what may be called the longer axes of their contortions, and lastly, to a certain small amount, by condensation. The chief result has obviously been due to the bending; but, in proof of elongation, it will be observed that the thickness of the bed *d f* is now about four times greater in those parts lying in the main direction of the flexures than in a plane perpendicular to them; and the same bed exhibits cleavage-planes in the direction of the greatest movement, although they are much fewer than in the slaty strata above and below.

Fig. 707.



(Drawn by H. C. Sorby.)

Vertical section of slate rock in the cliffs near Ilfracombe, North Devon.

Scale one inch to one foot.

a, b, c, e. Fine-grained slates, the stratification being shown partly by lighter or darker colours, and partly by different degrees of fineness in the grain.

d, f. A coarser-grained, light-coloured sandy slate, with less perfect cleavage.

Above the sandy bed *d f*, the stratum *c* is somewhat disturbed, while the next bed *b* is much less so, and *a* not at all; yet all these beds, *c*, *b*, and *a*, must have undergone an equal amount of compression with *d*, the points *a* and *g* having approximated as much towards each other as have *d* and *f*. The same phenomena are also repeated in the beds below *d*, and might have been shown, had the section been extended downwards. Hence it appears that the finer beds have been squeezed into a fourth of the space they previously occupied, partly by condensation, or the closer packing of their ultimate particles (which has given rise to the high specific gravity of such slates), and partly by elongation in the planes of the cleavage of which the general direction is perpendicular to that of the pressure. 'These and numerous other cases in North Devon are analogous,' says Mr. Sorby, 'to what would occur if a strip of paper were included in a mass of some soft plastic material which would readily change its dimensions. If the whole were then compressed in the direction of the length of the strip of paper, it would be bent and puckered up into contortions; whilst the plastic material would readily change its dimensions without undergoing such contortions; and the difference in distance of the ends of the paper, as measured in a direct line or along it, would indicate the change in the dimensions of the plastic material.'

Experimental demonstration of the origin of slaty cleavage.—Mr. Sorby has come to the conclusion that the absolute condensation of the slate rocks amounts, upon an average, to about one-half their original volume. Most of the scales of mica occurring in certain slates examined by Mr. Sorby lie in the plane of cleavage (see fig. 715); whereas in a similar rock not exhibiting cleavage they lie with their longer axes in all directions. May not their position in the slates have been determined by the movement of elongation before alluded to? To illustrate this theory, some scales of oxide of iron were mixed with soft pipeclay in such a manner that they inclined in all directions. The dimensions of the mass were then changed artificially to a similar extent to what has occurred in slate rocks, and the pipeclay was then dried and baked. When it was afterwards rubbed to a flat surface, perpendicular to the pressure, and in the line of elongation, or in a plane corresponding to that of the dip of cleavage, the particles were found to have become arranged in the same manner as in natural slates, and the mass admitted of easy fracture into thin flat pieces in the plane alluded to, whereas it would not yield in that perpendicular to the cleavage.

Tyndall, when commenting in 1856 on Mr. Sorby's experiments, observed that pressure alone is sufficient to produce cleavage, and that the intervention of plates of mica or scales of oxide of iron, or any other substances having flat surfaces, is quite unnecessary. In proof of this he showed experimentally that a mass of 'pure white wax, after having been submitted to great pressure, exhibited a cleavage more clean than that of any slate-rock, splitting into laminæ of surpassing tenuity.' He remarks that every mass of clay or mud is divided and subdivided by surfaces among which the cohesion is comparatively small. On being subjected to pressure, such masses yield and spread out in the direction of least resistance, small nodules become converted into laminæ separated from each other by surfaces of weak cohesion, and the result is that the mass cleaves at right angles to the line in which the pressure is exerted. In reply to Tyndall, Mr. Sorby pointed out that the white wax is really a crystalline substance made up of prismatic needles, as is seen when it is examined with a microscope, and under the influence of pressure these inequiaxed particles arrange themselves with their longer axes at right angles to the direction in which the force is applied.

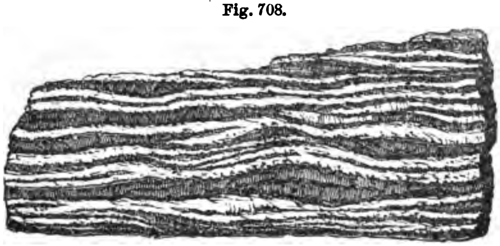
Darwin attributed the lamination and fissile structure of volcanic rocks of the acid series, including some obsidians in Ascension, Mexico, and elsewhere, to their having moved when liquid in the direction of the laminæ. The separation of the bands sometimes results from air-cells being drawn out and flattened in the direction of the moving mass.

Foliation of Crystalline Schists.—After studying, in 1835, the crystalline rocks of South America, Darwin proposed the term *foliation* for the structure that leads to the separation of gneiss, mica-schist, and other crystalline rocks into laminæ or plates. 'Cleavage,' he observes, may be applied to the structure in which divisional planes render a rock fissile, although it may appear to the eye quite or nearly homogenous. 'Foliation' may be used when the alternating layers or plates are of different mineralogical nature, like those of which gneiss and other metamorphic schists are composed.

It will be seen, then, that foliation differs from cleavage in the circumstance that the laminæ into which a cleaved rock breaks up are all of the same composition; while those of a foliated rock consist of distinct minerals like the quartz, felspar, and mica of gneiss (see fig. 708). The thin flakes making up a foliated rock, moreover, usually have a distinctly lenticular form, and may be spoken of as *folia*, rather than laminæ like those of slate. There is, however, the most perfect gradation from cleaved into foliated rocks.

That the planes of foliation of the crystalline schists in Norway accord very generally with those of original stratification is a conclusion long since espoused by Keilhau. Numerous observations made by the late David Forbes in the same country (the best probably in Europe for studying such phenomena on a grand scale) seemed to confirm Keilhau's opinion. In Scotland, also, Forbes pointed out what seemed to be a striking case where the foliation is identical with the lines of stratification, in rocks well seen near Crianlarich in Perthshire. There is in that locality a crystalline limestone, foliated by the intercalation of small plates of white mica, so

Fig. 708.



Fragment of gneiss, natural size; section made at right angles to the planes of foliation.

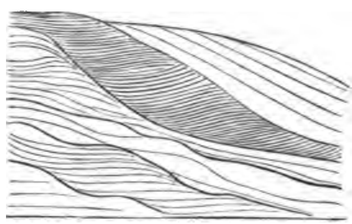
that the rock is often scarcely distinguishable in aspect from gneiss or mica-schist. The stratification is shown by the large beds and coloured bands of limestone all dipping, like the folia, at an angle of 32 degrees N.E. In stratified formations of every age we see layers of siliceous sand, with or without mica, alternating with clay, with fragments of shells or corals, or with seams of vegetable matter: and we should expect, Forbes argues, the mutual attraction of like particles to favour the crystallisation of the quartz, or mica, or felspar, or calcite along the planes of original deposition, rather than in planes placed at angles of 20 or 40 degrees to those of stratification.

After a general examination of the metamorphic rocks of the Highlands, Murchison and Geikie were led to the conclusion that, throughout the whole district, foliation is coincident with the stratification of the rocks, and not, as had been suggested by Daniel Sharpe, with their cleavage. Scrope, on the other hand, was inclined to attribute the foliation of the crystalline schists to 'the results of internal differential movements in the constituents of the subterranean mineral matter while exposed to enormous irregular

pressures as well as to variations of temperature, and under these influences changing at times from a solid to a fluid state, and probably back again to crystalline solidity, through intervening phases of viscosity—movements and changes which must *of necessity* have frequently arranged and rearranged the component crystalline minerals, sometimes in irregular composition like that of granite, diorite, or trachyte, sometimes in laminar or schistose bands like those of gneiss, mica-schist, and other so-called metamorphic crystallines.'

We have seen how much the original planes of stratification may be interfered with or even obliterated by concretionary action in deposits still retaining their fossils, as in the case of the Magnesian limestone of the Permian. Hence we must expect to be frequently baffled when we attempt to decide whether the foliation does or does not accord with that arrangement which gravitation, combined with current-action, imparted to a deposit from water. Moreover, when we look for stratification in crystalline rocks, we must be on our guard not to expect too much regularity. The occurrence of wedge-shaped masses (such as belong to coarse sand and pebbles), oblique lamination, ripple-marks, unconformable stratification, the fantastic folds produced by lateral pressure, faults of various widths, intrusive dykes, remains of organic bodies of diversified shapes, and other causes of irregularity in the planes of deposition, both on the small and on the large scale, will interfere with parallelism. If complex and enigmatical appearances did not present themselves, it would be a serious objection to the metamorphic theory. Mr. Sorby has shown that a structure which he compares to that of ripple-marked sands can be detected in certain varieties of mica-schists in Scotland.

Fig. 709.



Foliation of an argillaceous schist. Montagne de Séguinat, near Gavarnie, in the Pyrenees.

In the diagram (fig. 709) is represented the foliation of a coarse argillaceous schist in the Pyrenees (which was examined by Lyell in 1830). In part, it approaches in character to a green and blue roofing-slate, while part is extremely quartzose, the whole mass passing downwards into micaceous schist. The vertical section here exhibited is about three feet in height, and the layers are sometimes so thin that fifty may be counted in the thickness of an inch. Some of them consist of pure quartz. There is a resemblance in such cases to the diagonal lamination which we see in sedimentary rocks, even though the layers of quartz and of mica, or of felspar and other minerals, may be more distinct in alternating folia than they were originally.

General coincidence between Foliation and Cleavage in Metamorphic Rock-masses.—In spite of examples, like those just cited, in which the foliation of metamorphic rocks *appears* to follow the original lamination (or fine bedding) of a stratified mass,

there can be little doubt that, in the great majority of cases, the schistose structure is an entirely superinduced one, and that foliation, like cleavage, must be referred to the action of pressure, the planes of foliation being developed, like those of cleavage, at right angles to the direction in which the pressure is exerted. What were taken by David Forbes, and by Murchison and Geikie, as cases of the interbedding of rock-masses, with foliation parallel to the stratification, have been proved by the researches of Professor Lapworth and the officers of the Geological Survey to be really examples of rock-masses brought into juxtaposition by great reversed faults (thrust-planes), see fig. 631, p. 436. Simulations of 'false-bedded' and 'ripple-mark' structures like those referred to in the Pyrenees appear to often result from changes in the direction of pressure in a great mass undergoing folding movements which lead to the appearances known as Ausweichungs-Clivage (the 'strain-slip cleavage' of Professor Bonney). Such being the case, we can understand the phenomena to which attention was drawn by Darwin in South America, where over vast areas cleavage and foliation everywhere maintain a marked parallelism; the *strike* of the cleavage and foliation being coincident with that of the stratification, but the *dip* of the planes of cleavage being inclined, often at a very high angle, to those of bedding.

Experimental Illustrations of Dynamo-metamorphic action.—By the method of sealing up various substances in glass tubes with water and exposing them to high temperatures, so that the confined vapour of the water exercises a powerful pressure within the tube, Daubrée and other French chemists and mineralogists have shown that many crystallised minerals may be produced. Glasses, both natural and artificial, which are amorphous mixtures of various silicates, were found to break up under these conditions, and their various constituents recombined and crystallised out as quartz, sanidine, wollastonite, diopside, and other well-known mineral species. In this way a very considerable proportion of the minerals composing the earth's crust has been artificially prepared; the crystals, though often of microscopical dimensions, presenting all the distinguishing characters of the natural ones.

Professor W. Spring, of Liège, has carried on a series of experimental researches upon the effects of pressure apart from those of high temperature. In these experiments, pressures estimated to exceed 7,000 atmospheres were employed, and the precaution was taken of applying the force so slowly that any heat generated would be dissipated, and would not interfere with the result. The conclusions at which Spring arrived were as follows:—

1. Powders of metals and other solids may, by intense pressure (especially if all interstitial air-films be removed by the action of an air-pump) be converted into solid masses indistinguishable from those produced by fusion. In powders and colloid masses pressure will produce a perfectly crystalline structure.

2. Where elements have allotropic forms, or compounds are heteromorphous, the less dense substance may be converted into the heavier by the action of pressure. Van 't Hoff and Reicher have also shown that the temperature at which all such paramorphic changes take place is modified by pressure.

3. Powders of metals, oxides and salts may by pressure be made to react chemically upon one another—without the intervention of

any liquid or gas—and alloys are produced, various salts formed, and double decompositions brought about under such conditions.

4. The rubbing or sliding of the particles of solid bodies over one another under intense pressure powerfully promotes chemical action between them.

5. When the particles of solid bodies have been brought into contact by intense pressure, the chemical action between them goes on, even when the pressure is removed.

6. The action of pressure on solids is variously modified by the presence of small quantities of water or of various gases.

The late Dr. Guthrie and other physicists and chemists have shown, by the study of solutions under pressure, that there is a perfect continuity between the states of solution and fusion. As was maintained by Bunsen, the various mixtures of silicates, which constitute igneous rocks, are really solutions at high temperatures, the solvent being sometimes a fusible silicate, often mixed with more or less water under pressure.

A very good summary of our knowledge on the cleavage of rocks will be found by the student in the essay of Mr. Harker on the subject, Brit. Assoc. Rep. 1885. For a discussion of the action taking place in the metamorphism of rocks he is referred to Delessé's 'Études sur le Métamorphisme des Roches,' to Daubrée's 'Géologie Expérimentale,' and to J. Lehmann's 'Alltkrystallinische;' and for an account of Spring's researches to 'Journ. Chem. Soc.' 1890, p. 404.

CHAPTER XXXIX

CONTACT METAMORPHISM AND REGIONAL METAMORPHISM: THE VARIETIES OF ROCKS RESULTING FROM THESE TWO KINDS OF ACTION

Illustrations of the action of Contact Metamorphism—Distance to which Contact Metamorphism can be traced from the intrusive mass—Minerals produced by Contact Metamorphism—Chief types of Rocks produced by Contact Metamorphism—Andalusite, Kyanite, Sillimanite, Staurolite Rocks, &c.—Rocks produced by Regional Metamorphism, Quartzites, Metamorphic Limestones, and Dolomites, Slates, Phyllites, Schists, Gneisses, Granulites, Anthracites, &c.

As we have seen in the last chapter, contact metamorphism is largely the result of the action of heat, while in the case of regional metamorphism the action of heat is greatly modified by, and even subordinated to, that of pressure. Hence we are not surprised to find that the rocks formed by contact and regional metamorphism respectively, while having many features in common, nevertheless often present dissimilar and distinctive characters.

Fossiliferous strata rendered metamorphic by intrusive masses.—In treating of the nature of intrusive veins of volcanic

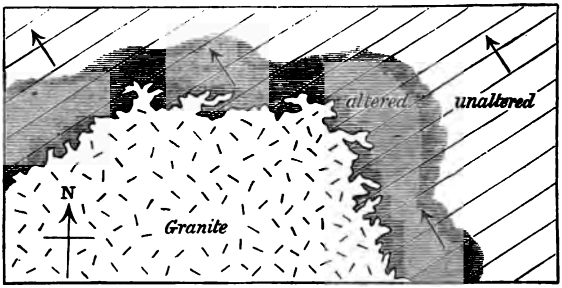
and plutonic origin (p. 447), examples were given of alterations in the affected rocks by heat and percolating water containing chemical matters. The subject was further illustrated in noticing the methods of distinguishing the age of volcanic rocks (p. 485). It is, therefore, only necessary to cite a few additional instances of local metamorphism.

In the southern part of Norway there is a large district, on the west side of the fiord of Christiania (which Lyell visited in 1837 with the late Professor Keilhau) in which hornblendic granite protrudes in mountain masses through fossiliferous strata, usually sending veins into them at the point of contact. The stratified rocks, replete with shells and corals, consist chiefly of shale, limestone, and some sandstone, and all these are invariably altered near the granite for a distance of from 50 to 400 yards. The shales are hardened, and have become flinty, sometimes resembling jasper. Ribboned jasper is produced by the hardening of alternate layers of green and chocolate-coloured shale, each stripe faithfully representing the original lines of stratification. Nearer the granite the altered shale often contains crystals of hornblende, which are even met with in some places, for a distance of several hundred yards from the junction; and this black hornblende is so abundant that eminent geologists, when passing through the country, have confounded it with the ancient hornblende-schist, subordinate to the great gneiss formation of Norway. Frequently, between the granite and the hornblende-slate above mentioned, crystalline grains of mica and felspar appear in the schist, so that rocks resembling gneiss and mica-schist are produced. Fossils can rarely be detected in these schists, and they are more completely effaced in proportion to the more crystalline texture of the beds and their vicinity to the granite. In some places the siliceous matter of the schist becomes a granular quartzite; and when hornblende and mica are added, the altered rock loses its stratification, and resembles granite. The limestone, which at points remote from the granite is of an earthy texture and blue colour, and often abounds in corals, becomes a white granular marble, sometimes siliceous, near the granite—the granular structure extending occasionally upwards of 400 yards from the junction; the corals are for the most part obliterated, though sometimes preserved, even in the white marble. Both the altered limestone and the hardened slate contain garnets in many places, with ores of iron, lead, and copper, and some silver. These alterations occur equally, whether the granite invades the strata in a line parallel to the general strike of the fossiliferous beds, or in a line at right angles to their strike, both of which modes

of junction will be seen by the accompanying ground-plan (fig. 710).

The granite of Cornwall sends forth veins into a coarse argillaceous schist, locally termed killas. This killas is converted into hornblende-schist near the contact with the veins. These appearances are well seen at the junction of the granite and killas in St. Michael's Mount, a small island nearly 300 feet high, situated in the bay, at a distance of about three miles from Penzance. The granite of Dartmoor, in Devonshire, according to De la Beche, has intruded itself into the Carboniferous slate and slaty sandstone, twisting and contorting the strata, and sending veins into them. Hence some of the slate rocks have become 'micaceous;' others much indurated, exhibit characters of mica-slate; while others again are converted into a hard, banded rock with much felspar resembling gneiss.

Fig. 710.



Ground-plan of altered slate and limestone near granite, Christiania.
The arrows indicate the dip, and the oblique lines the strike of the beds.

Nowhere, however, are the phenomena of local metamorphism more beautifully illustrated than in the Western Isles of Scotland. In this district, great masses of granite and gabbro have been thrust through the various Palæozoic and Secondary strata, during the Tertiary period; and in the vicinity of the junctions of the igneous and the sedimentary masses most instructive examples of metamorphism may be observed. Thus limestones of the same age as those of Durness (Cambrian) are found losing, as we approach the igneous rocks, all traces of their organic remains, and at last passing into a highly crystalline or saccharoid marble suitable for statuary purposes. Clays and sandstones of various ages, under like conditions, are also found to be deprived of every trace of the organic structures originally present in them and to graduate into indurated slaty rock and

quartzite, while the felspathic sandstones of the Cambrian are altered to a highly micaceous quartzite.

We learn from the investigations of M. Dufrénoy, that in the Eastern Pyrenees there are mountain masses of granite, posterior in date to the formations called Lias and Chalk of that district, and that these fossiliferous rocks are greatly altered in texture, and often charged with iron-ore, in the neighbourhood of the granite. Thus in the environs of St. Martin, near St. Paul de Fénouillet, the chalky limestone becomes more crystalline and saccharoid as it approaches the granite, and loses all trace of the fossils which it previously contained in abundance. At some points, also, it becomes dolomitic, and filled with small veins of ferrous carbonate and spots of red hematite.

The local metamorphism of carbonaceous beds, such as coal-seams, is very interesting. The most simple result of the intrusion of a dyke of basalt, for instance, amongst Coal-measures is for the coal to become hard and brittle, to lose its more volatile matters, and to change into anthracite, or even into graphite, and this may take place 50 yards away from the basalt. Close to the dyke, the coal may be reduced to the form of cinder, occupying a much smaller space than before; or, as in South Staffordshire, the coal may become sooty and coked. Distillation arising from the heating and alteration of coal and bituminous shales by the action of igneous intrusions causes the gases to find their way to the surface, and the liquid products to collect in fissures and cavities. Petroleum and asphalte are thus collected in chinks of sandstones and other sedimentary rocks, and even of the igneous rocks themselves, while natural gases (hydrocarbons) find their way to the surface.

Prismatic structure, resembling miniature basaltic columns, has often been produced in coal by this local metamorphic action.

On the other hand, the igneous rock has often been altered by contact with the coal, becoming white, or yellow, earthy. light, and friable. This 'white trap,' as it is called, has had its crystalline structure nearly destroyed, much of its silica and lime removed, while its iron remains to form ferrous carbonate.

Extent of Contact Metamorphism.—Contact metamorphism is always distinguished by its local character; in some cases the alteration produced can only be traced for a few feet or even inches from the planes of junction with the igneous mass; and in few instances probably can such changes be detected at distances of over two miles. Usually, the amount of alteration increases as we approach the igneous rock, but there are some very remarkable cases in which apparent exceptions to this rule are found. The different kinds of rocks undergo very variable amount of change,

according to their chemical composition, and thus it sometimes happens that in the metamorphic zones surrounding great intrusive masses we find alternations of rocks which are much altered with others showing few signs of change. Where contact metamorphism is extreme, a very marked foliation is always developed. As a rule, the extent of metamorphism, and the distance to which it can be traced, bear a marked relation to the volume of the intrusive mass around which it is exhibited. But it should be remembered that in some cases the igneous rock may have been simply injected into the surrounding rocks, while in other cases the liquid mass may have been forced for ages through the fissure which has served as a means of communication with the surface. The amount of chemical action in the latter case would, of course, be far greater than in the former. It is worthy of notice that the minerals produced in limestones and other rocks in contact with igneous masses are identical with those found in the fragments of much-altered materials that are thrown from volcanic vents.

Not only do we find all kinds of sedimentary materials undergoing alteration around plutonic rock-masses, but volcanic and older plutonic rocks are likewise changed, while metamorphic rocks are subjected to still further metamorphism.

Chief varieties of minerals produced by Contact Metamorphism.—The principal changes produced by the thermal or hydrothermal action taking place around igneous intrusions consist in the development of various crystalline minerals in the mass. Most of these minerals appear to be formed from the various elements already existing in the rock, these entering into new combinations and forming crystals often of great beauty and perfection. But, in many cases, there can be no doubt that substances contained in the intrusive mass react on the materials into which it is thrust, and minerals are formed which could not be produced by simple metamorphism. Of such *metasomatic* changes, as they are called, we have examples in the formation of tourmaline, axinite, fluorspar, &c., through the action of the boric, hydrofluoric acid, and other gases given off from great intrusive masses—like the granite of Dartmoor—acting on the silicates of the invaded rock, and in the impregnation of metallic sulphides so frequently found near the contact of igneous and other rock masses. On the other hand, we not unfrequently find evidence that the igneous rock itself is affected by the contact with materials among which it is intruded. Fragments of the surrounding rock are torn off, being fused and absorbed in the liquid and highly heated mass, and new minerals are formed during its crystallisation.

All the ordinary rock-forming minerals—quartz, the various felspars, and many ferro-magnesian silicates—are formed by contact metamorphism; varieties of biotite are especially abundant, and forms of hornblende are by no means rare. There are certain silicates—for the most part highly aluminous ones—which are particularly abundant in, and generally characteristic of, the metamorphosed argillaceous rocks. Among the most important of these are andalusite, sillimanite or fibrolite, and kyanite, with garnet, staurolite, cordierite, epidote, and zoisite. Many of these minerals are very unstable, and we frequently find in the metamorphosed rocks, not the minerals themselves, but the products of their alteration,

such as muscovite and its hydrated forms (damourite, sericite, &c.), pinites, kaolin, the chlorites, ottrelite, and other chloritoids, the vermiculites, &c. Many of the rocks undergoing contact metamorphism are seen to exhibit spots and markings, showing that a segregative action has gone on in the mass, and between these obscure markings and fully developed crystals of biotite, hornblende, garnet, andalusite, &c., we find every intermediate gradation (see fig. 711). The structure of these 'spotted slates' ('flecktschiefer,' 'garbenschiefer,' &c., of the Germans) is admirably displayed in thin sections under the microscope, and changes by which the passage of amorphous and fragmental materials into beautifully crystallised minerals is effected, can be distinctly traced. Some of the garnets and other minerals found in the rocks altered by contact metamorphism are of large size, perfectly clear, and free from foreign inclusions. But in other cases, much uncrystallised material is found caught up in

Fig. 711.

Spotted slate from Saxony. The smaller dark-coloured spots are incipient crystals of biotite; the larger and paler-coloured ones are hornblende. In both, the work of crystallisation is incomplete, and they include much amorphous material distributed through a base with crystalline properties.

Fig. 712.

Chiastolite-slate, from Bavaria. The white spots are sections (longitudinal and transverse) of the variety of andalusite known as chiastolite. In these, the amorphous matter, instead of being irregularly distributed through the crystals, is arranged in cross-shaped patterns within them. The material around these crystals is but little altered.

the crystals during their growth, and this sometimes shows a remarkable symmetrical arrangement within the mineral, as in the form of andalusite known as 'chiastolite' (see fig. 712).

Rocks produced by Contact Metamorphism.—Purely siliceous sands and sandstones are altered by contact metamorphism into a quartzite or quartz-rock, the grains of quartz, besides being cemented into a solid rock, sometimes having the aqueous solutions or carbon dioxide expelled from their cavities, and occasionally exhibiting signs of partial fusion or even of complete recrystallisation (see fig. 713). More felspathic or micaceous sandstones may have many secondary minerals developed in them, and the rock may become distinctly foliated (quartz-schist). Very impure sandstones, grits, and arkoses pass into siliceous schists, and even into rocks, which must be classed as true gneisses.

It is in the case of the argillaceous rocks that we find the greatest variety of products resulting from the action of contac

metamorphism. When fine-grained siliceous clays are exposed to the action of heat by contact with igneous masses, they pass into the hard compact materials often called hornstones, porcellanites, ribboned jasper, Lydian stone, &c., and in some of these materials traces of the fossils contained in the original rocks may still be detected. But clays, shales, and slates are also found passing into spotted slates of different kinds, and then into mica-slates, andalusite- and chiastolite-slates, cordierite-slates, ottrelite-slates, &c. Garnets are frequently developed in great numbers, but of microscopic dimensions; and in this way are produced some of the materials most valued as whetstones, like the celebrated Water-of-Ayr stone. In other cases the micaceous minerals assume a parallel arrangement, large garnets are developed with staurolite, andalusite, cordierite, and many other minerals, and the whole mass passes into a foliated rock very similar to the product of regional metamorphism.

Fig. 713.

Quartzite, from Saxony, made up of grains of clear quartz with cloudy felspars. The rock has probably been produced by the metamorphism of a felspathic sandstone or greywackè; the outlines of the grains being still distinguishable.

Fig. 714.

Impure crystalline limestone, from Styria. Clear crystalline grains of calcite are seen, traversed by the characteristic twinning and cleavage-planes, with some quartz-grains containing streams of liquid-cavities and opaque particles of graphite.

Pure limestones become completely recrystallised by the action of metamorphism, and aggregates of calcspar crystals—each marked by the peculiar twinning and cleavage of the mineral—are formed, giving rise to the well-known saccharoid or statuary marble (see fig. 714). In some cases, magnesian compounds appear to be introduced into a calcareous rock during contact metamorphism, and magnesian limestones, and even true dolomites, result from the action. When the limestone contains impurities, new crystalline minerals are formed, such as tremolite, actinolite, various micas, wollastonite, felspars, zoisite, lime-garnets, quartz, &c. ('calciphyres'). The rocks thus formed occasionally exhibit a distinct foliation, and calc-schists ('cipolinos') are produced, indistinguishable from those resulting from regional metamorphism. Many of the most beautiful marbles, and rocks containing the greatest variety of crystallised minerals—like those of Monzoni in the Tyrol—appear to be the result of the action of contact metamorphism on limestone rocks.

That igneous and metamorphic rocks are also subjected to

contact metamorphism has been already pointed out. In some cases, the minerals produced by weathering, like kaolin, chlorites, calcites, chalcedony, &c., are altered back to others similar to those which existed in the original rocks. In other cases, new minerals have been formed, like albite, hornblende, epidote, sphene, with pyrites and other sulphides—the latter being due in part at least to the introduction of certain materials given off by the igneous magma which has invaded the rocks.

Regional metamorphic Rocks.—These rocks, when in their most characteristic development, are wholly devoid of organic remains, and contain no distinct fragments of other sedimentary rocks. Gneiss and mica-schist may be taken as typical examples. But phyllites and some schists (the former sometimes still containing fossils or their impressions) may be considered to be less altered varieties. They sometimes appear in the central parts of mountain chains, but in other cases extend over areas of vast dimensions, occupying, for example, nearly the whole of Norway and Sweden, where, as in Brazil, they appear alike in the lower and higher grounds. However crystalline these rocks may become in certain regions, they seldom, like granite, send veins into contiguous formations. In Great Britain, those members of the series which approach most nearly to granite and other plutonic rocks in their composition, as gneiss, mica-schist, and hornblende-schist, are chiefly found in the country north of the rivers Forth and Clyde, in Wales, the Malverns, and Leicestershire (Charnwood Forest).

Many attempts have been made to trace a general order of succession or superposition in the members of this family; clay-slate, for example, having been often supposed to hold invariably a higher geological position than mica-schist, and mica-schist to overlie gneiss. But although such an order may prevail throughout limited districts, it is by no means universal. The mechanical peculiarities of these rocks are expressed by the terms 'cleavage' and 'foliation.'

We have seen that sedimentary rocks in the immediate proximity of great igneous intrusions are found to have undergone great induration, while the development of various crystalline minerals has frequently taken place in them. In cases where the action of contact metamorphism has been extreme, we have shown that a very distinct foliation is often developed in the altered rocks. The similarity of the rocks thus formed—especially where the metamorphism has been extreme—to many of the foliated or schistose rocks, characteristic of regional metamorphism, suggests that the latter may have been produced from pre-existing strata by the action of analogous chemical

forces operating on a more extended scale. Thus gneiss and mica-schist may be nothing more than altered felspathic and micaceous sandstones, granular quartzite may have been derived from pure sands and sandstone, and the most highly crystalline quartzite may be the last stage of alteration of the same materials. Similarly, clay-slate and many forms of schist may be altered shale, and granular marble may have originated in an ordinary limestone, replete with shells and corals, which have since been obliterated; and, lastly, calcareous sands and marls may have been changed into impure crystalline limestones.

The anthracite and graphite associated with regional-metamorphic rocks may have been coal; for not only is coal converted into anthracite in the vicinity of some trap dykes, but we have seen that a like change has taken place generally even far from the contact of igneous rocks, in the disturbed region of the Appalachians. At Worcester, in the State of Massachusetts, 45 miles due west of Boston, a bed of plumbago or impure graphite occurs, interstratified with mica-schist. It is about feet in thickness, and has been made use of both as fuel and in the manufacture of 'lead-pencils.' At the distance of 30 miles from the plumbago, there occurs, on the borders of Rhode Island, an impure anthracite in slates containing impressions of coal-plants of the genera *Pecopteris*, *Neuropteris*, *Calamites*, &c. This anthracite is intermediate in character between that of Pennsylvania and the graphite of Worcester, in which last the gaseous or volatile matter (hydrogen, oxygen, and nitrogen) is to the carbon only in the proportion of 3 per cent. (After traversing the country in various directions, Lyell came to the conclusion that the Carboniferous shales or slates with anthracite and plants, which in Rhode Island often pass into mica-slates, have at Worcester assumed a perfectly crystalline and metamorphic texture: the anthracite having been nearly transmuted into that state of pure carbon which is called plumbago or graphite.)

The alterations already described as being superinduced in rocks by volcanic dykes and granite veins prove incontestably that powers exist in nature capable of transforming clastic and fossiliferous strata into crystalline rocks.

But while all the sedimentary rocks undergo more or less complete recrystallisation, with or without the development of a foliated structure, like changes may affect all kinds of volcanic, plutonic, and metamorphic rock-masses. Tuffs and lavas, as well as the several varieties of crystalline rocks, may thus be converted into schists and gneisses. It is probable that many

of the gneisses and schistose rocks which we now see exposed at the earth's surface have undergone not one cycle of change but many repeated metamorphoses. All the materials of the earth's crust, indeed, tend to pass through regular cycles of change, granites and the crystalline rocks being broken up by denuding agencies at the surface to form clastic sedimentary rocks, and these, when buried at great depths, being subjected to metamorphic action whereby they pass into schists, and even into gneiss, in which last all traces of foliation may disappear, when the rock becomes a granite. Such being the case, it is of course impossible to say from what particular variety of aqueous, igneous, or metamorphic rock a given gneiss or schist has been formed. The ultimate chemical composition of such rocks as

Fig. 715.

Clay-slate. North Wales. Section cut transversely to the cleavage. The flattened grains are all seen with their longer axes lying in the direction of the cleavage, or at right angles to the direction in which the pressure has acted which produced that structure. The flattened grains consist of kaolin and other micaceous minerals.

Fig. 716.

Contorted mylonite. Loch Maree. The rock is made up of crushed and re-cemented particles. The breaking-up of the mass has been produced along fault- (or 'thrust'-) planes. The 'cataclastic' structure is especially well seen under polarised light, the different orientation of the crystal particles being thus made visible.

quartzites and limestones of course indicates that they must have been formed from arenaceous or calcareous strata, but there are many schists, granulites, and even gneisses, which, so far as their ultimate chemical composition indicates their origin, may have been equally formed from igneous or sedimentary materials.

Rocks formed by regional Metamorphism.—Among the least altered of the rocks affected by dynamo-metamorphic action are the clay-slates, and the rocks called by Professor Lapworth 'mylonites.' Clay-slates retain many of the ordinary characteristics of a clay or shale, though with a slightly increased density. But sections of slate cut transversely to the cleavage, when examined under the microscope, exhibit a remarkable parallelism of their

particles, all the rods and flat plates in the mass having had their positions rearranged so that they lie at right angles to the direction of the pressure which has acted upon them (see fig. 715). Mylonites are composed of the fine dust or fragments of rocks which have been crushed to powder along great fault-planes (or 'thrust-planes'), these fine particles being consolidated and often partially recrystallised (see fig. 716). Many metamorphic rocks exhibit a similar 'cataclastic' structure. Where pebbles and other included masses have existed in the rock they are often fractured and sometimes crushed and broken, the fragments being sometimes torn apart from one another by the shearing movements within the mass. In the same way, metamorphic rocks which contain porphyritic crystals sometimes exhibit this cataclastic structure in a very marked manner, the large felspar-crystals having their edges and angles rounded off, so as to form the eyes ('Augen') of the so-called Augengneiss (see fig. 720).

Fig. 717.

Phyllite. Saxony. Made up of clastic materials mingled with crystals of biotite and other micaceous minerals of secondary origin, developed along the planes of cleavage.

Fig. 718.

Chlorite-schist. Moravia. Made up of crystalline particles of chlorite and magnetite, showing a distinct foliation. Other minerals are occasionally present in the rock.

In the majority of cases, however, the movements producing cleavage and shearing in a rock-mass are attended with a certain amount of recrystallisation, as well as deformation and crushing. Thus we often find the surfaces of slaty rocks covered with crystals of mica and other minerals which are evidently of secondary origin and have been produced during the movements to which the rock-masses have been subjected. Such rocks are usually called in England mica-slates, talcose-slates, chlorite-slates, &c. (after the mineral most distinctly exhibited in them), in contradistinction to the clay-slates in which no such secondary minerals are apparent in the cleavage-planes. In France, rocks of this class are usually called *phyllites* (see fig. 717); there are phyllites, as has been shown by Professor Reusch, of Christiania, which exhibit recognisable traces of corals, trilobites, and other fossils, which remain in spite of the partial recrystallisation of the materials of the rock.

When the whole, or nearly the whole, of the materials of a rock have been recrystallised, so that it is made up of thin folia of quartz and of some other minerals, the rock is called a *schist.*

The term 'schist' is, however, used in a much more general manner in Germany, being sometimes applied to phyllites and even to clay-slates and shales. The different kinds of schist are named after the most conspicuous mineral present in them, such as mica-schists

Fig. 719.

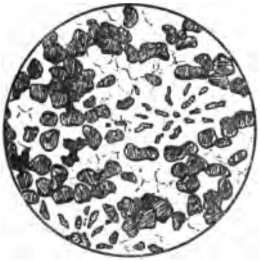
Mica-schist with garnets. Made up of folia of mica (distinguished by its distinct basal cleavage) and quartz with large garnets (one is seen in the lower part of the section) interspersed through the mass.

Fig. 720.

Hornblende-gneiss, with 'eyes' (Augen-gneiss). The large deformed crystals consist of felspar or, more rarely, hornblende (one example with characteristic cleavage is seen in the lower part of the section).

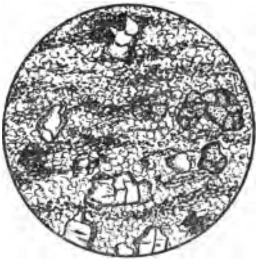
(see fig. 719), talc-schists, chlorite-schists (see fig. 718), hornblende-schists, actinolite-schists, tremolite-schists, epidote-schists, piedmontite-schists, &c. These schists often contain additional minerals —identical with those found in rocks formed by contact meta-

Fig. 721.



Pyroxene-granulite ('trap-granulite'). Saxony. Made up of colourless grains of felspar and quartz, with augite, hypersthene, and garnet. The intergrowth of felspar and garnet gives rise to the 'centric' structure seen near the middle of the section.

Fig. 722.



Granulite, with kyanite. Saxony. Rounded granules of quartz and orthoclase felspar make up the mass of the rock, through which are scattered larger grains of garnet and kyanite (the former mineral is seen on the right of the section).

morphism—such as garnet, cordierite, kyanite, sillimanite or fibrolite, kyanite, &c.

The metamorphic rocks which contain felspar form the two classes of the *granulites* and the *gneisses*. These have often the

same ultimate chemical composition as igneous rocks, both basic and acid, though some of them are not improbably the result of the extreme metamorphism of arkoses, felspathic sandstones (grey-wackés), micaceous flagstones, and similar sedimentary rocks. (See table of analyses, p. 588.) The distinctive structure of the granulites is seen in a rock when all the minerals present more or less rounded grains which fit together, so that under the microscope the sections resemble mosaics. The basic or pyroxene-granulites ('trap granulites') consist of felspars of different species with one or more forms of pyroxene (augite, hypersthene, &c.), sometimes replaced by hornblende or biotite; in addition, garnets are almost always present sometimes in considerable quantities (see fig. 721). The acid or common granulites (*leptynites* of the French and *Weissstein* of the Germans) contain much felspar, orthoclase usually predominating with quartz and garnet, to which kyanite is frequently added (see fig. 722). The most common gneisses are of acid composition and agree in their mineralogical composition with the granites, granitites

Fig. 723.

Micaceous gneiss. Saxony. Made up of folia of quartz, felspar, and mica. The rock has the mineralogical constitution of an ordinary granite, with a very distinct foliation.

Fig. 724.

Pyroxene-gneiss. Ceylon. Very coarsely crystalline. The clear crystals are quartz and scapolite, the clouded ones a basic plagioclase felspar, and the dark-coloured ones a green augite.

and quartz-diorites, but are distinguished from these by their more or less distinct foliated structure (see fig. 723). The so-called protogine-gneisses have much hydrous white mica (sericite), and some gneisses contain many accessory minerals, such as garnet, cordierite, andalusite, sillimanite or fibrolite, kyanite, &c. In addition to these common or acid gneisses, there are others which correspond in composition with the pyroxene-granulites and contain much basic felspar (labradorite or anorthite) with quartz, and some pyroxene (sahlite, ægerine, hypersthene, &c.), these minerals being sometimes replaced by hornblende or biotite. Many accessory or secondary minerals, such as scapolite, wollastonite, fibrolite, garnet, &c., occur in these basic or 'pyroxene'-gneisses (see fig. 724).

The gneisses are sometimes very coarsely grained rocks; they not unfrequently contain porphyritic crystals of felspar and other minerals, these being sometimes converted by crushing movements into 'eyes' (Augengneiss, fig. 720). The foliation of gneiss is often

so obscure that it can only be seen when great rock-masses are studied in the field.

Plutonic rocks, like granite, diorite, and gabbro, not unfrequently present both the granulitic and the gneissic structures; and when such structures are exhibited by these rocks it can generally be shown that they have been subjected to movements while in a plastic or semi-plastic condition, so as to have a 'flow-structure' developed in them. The distinction between granulitic gabbros or norites of igneous origin and pyroxene-granulites, of metamorphic origin, is often very doubtful and obscure; and in the same way it is often impossible to decide if a rock should be rightly described as a gneiss-granite or a granitic gneiss. Schists, granulites, and gneisses, even when derived from sedimentary rocks by metamorphism, cannot be expected to exhibit traces of fossils, for all their materials have been completely recrystallised.

It has been shown how insensible are the gradations from various sedimentary rocks, altered by contact metamorphism into true schists and gneisses; and on the other hand how difficult it is to discriminate between certain structural varieties of undoubted plutonic rocks and the granulites and gneisses. These facts point to the conclusion that the rocks now exposed in the earth's crust may all really have passed through those cycles of change which we have been describing. No good reasons have been adduced for asserting that any of the highly crystalline rocks—whether foliated or not—were originally part of the globe as it first consolidated from a state of igneous fusion, or that the causes which are now acting upon and within the earth's crust were ever different in kind or in order of magnitude from those which are operating at the present day.

For further information on the metamorphic rocks the student is referred to petrographical text-books like that of Zirkel ('Lehrbuch der Petrographie,' 3rd ed., 1895). An excellent summary of the subject will be found in Harker's 'Petrology for Students' (1895), pp. 254–302.

CHAPTER XL

THE FORMATION OF MOUNTAIN-CHAINS

Various types of Mountain-chains—Majority of Mountain-chains belong to Appalachian type—Structure of the Scottish Highlands and similar denuded Mountain-chains—Mountain forms due proximately to denudation—Sequence of events in Mountain-making—Geo-synclinals—Ge-anticlinals—Mountain sculpture.

Different kinds of Mountain-chains.—From what has been said in the preceding chapter, it will be inferred that the production of regional metamorphism is intimately connected with the folding and faulting of rock-masses, which have played such an important part in the formation of the great mountain-chains

of the globe. There are, it is true, mountains and mountain-chains in which metamorphic rock-masses do not appear. Thus we have mountains of volcanic origin of the grandest dimensions; the tops of the great lava-cones that rise above the surface of the Pacific to form the Sandwich Islands are nearly 30,000 feet above the ocean-floor on which they stand, and in the Andes such volcanic mountains unite to form a considerable chain. In the district of the Jura, and in the western territories of the United States, we find examples of mountain-chains which owe their origin to uniclinal (monoclinal) or anticlinal foldings of the strata, or to the upheaval of rocks capable of resisting denudation along great lines of fault. In all cases it must be observed that the proximate cause of the forms assumed by mountain-masses is the action of subaërial denudation, which is especially powerful in the higher regions of the atmosphere.

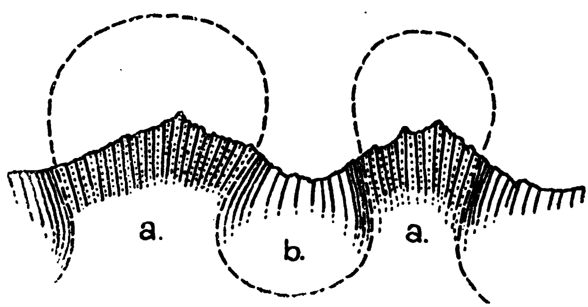
Appalachian type of Mountain-chains.—In spite of the fact that there are certain types of mountains which have originated from causes other than those connected with the lateral movements in the earth's crust that produce the folding, fracturing, and foliation of rock-masses, it is clear that the majority of mountain structures, both in past and present times, must have owed their existence to these latter agencies. This conclusion was first fairly brought home to the minds of geologists by the brothers W. B. and H. D. Rogers, in their investigation of the structures of the Appalachian Mountains. It was shown by these authors that not only are the strata greatly folded and faulted as we approach the central axis of the mountain-chain, but that great reversed faults can be traced for more than eighty miles, along which one series of rocks is seen to be forced over another, sometimes for distances of twenty miles. For such great reversed faults—the hade of which may sometimes nearly correspond with the horizontal plane—the name of 'thrust' has since been suggested. The two authors, to whom we have referred, clearly demonstrated the origin of those types of structure which are so constantly exemplified in mountain-chains; they showed that ordinary symmetrical anticlinal and synclinal folds like those we have described in preceding pages, yielding to lateral pressure, have their axis plane pushed over farther and farther from the vertical position (see fig. 725 *a*), and that the strain on the 'middle-limb' of the fold eventually leads to elongation and fracture (see fig. 725 *b*); this, if the tangential pressure continues to act, results in the formation of a typical 'thrust' (see fig. 725 *c*), which is nothing but a greatly exaggerated reversed fault. One of the authors named, the late Professor H. D. Rogers, subsequently visited the Alps and showed that

the features described in the Appalachians were repeated on even a grander scale in the Alps. The studies of Heim and other Swiss geologists have confirmed in the most striking manner the conclusions of the American geologists, and have served to explain how the features known as 'fan-structure'

Fig. 725.

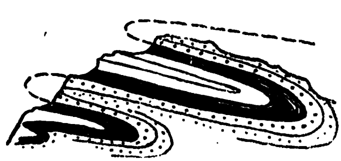
a. Overfolded strata. *b*. Overfold passing into reversed fault.
c. Overthrust (the plane of faulting is often called a 'thrust-plane').

Fig. 726.



'Fan structure,' resulting from lateral pressure. At *a*, *a* the opening out of the strata is directed upwards, at *b* downwards.

Fig. 727



Strata showing 'double isoclinal overfolding.'

(see fig. 726), and multiple folding (see fig. 727), can be explained by the great lateral or tangential pressures to which the rock-masses have been subjected.

Structure of the Scottish Highlands.—Nearly thirty years ago Professor J. Nicol in seeking to explain the relations of

the rock-masses of the North-West of Scotland (see figs. 629, 630, p. 436), invoked the aid of similar lateral thrusts to those described by Rogers in the Appalachians and the Alps; and though his views were opposed so long and so strenuously by Murchison and Geikie, their correctness has been established by the later labours of Messrs. Lapworth, Peach, Horne, and other observers (see fig. 631, p. 436). By these researches it has been made manifest that—just as we may often learn more about the nature and effects of volcanic action by investigating the greatly denuded basal wrecks of old volcanoes, than by studying volcanoes in actual eruption—so the researches carried on in districts like Central Europe, Scandinavia, and the Highlands of Scotland may throw more light on the origin of mountains and the causes of metamorphism than is to be gained by a study of the Alps and the Himalayas.

Effects of denudation in Mountain-chains.—In connection with this subject it should be pointed out that all the great mountain-chains at present existing on the globe are of very recent age, geologically speaking. All great mountain-chains must be young mountain-chains; for so rapid is the work of subaërial waste in the higher regions of the atmosphere, that the mountain-chains of the earlier geological periods are now reduced to 'basal-wrecks;' but in these it is often possible to study the results of the action of the forces engaged in mountain-making, in a way that is not possible in mountain-chains which have been less completely dissected by denudation.

Origin of Mountain-chains.—The systematic study of the origin of mountain-chains, begun by the brothers Rogers more than fifty years ago, has been admirably followed up by Dana and other American geologists, and it is largely owing to their efforts that we are now able to trace the succession of operations which, in the end, result in the formation of a great mountain-chain.

Geo-synclinals.—Mountain-ranges, as pointed out by Suess, usually originate along lines of weakness in the earth's crust: indeed a mountain-chain may be regarded as a cicatrised wound in the earth's solid crust. The original line of weakness may or may not be indicated by volcanic outbursts taking place along it; but in all cases the initial stage in the development of a mountain-range consists of a slow but prolonged subsidence in that part of the crust which is afterwards to become a mountainous mass. The slowness of this subsidence is indicated by the fact that many thousands of feet of strata, some of them of littoral or shallow-water origin, accumulate during many successive geological periods on the subsiding ocean floor. In this way is formed what the American geologists call a geo-synclinal, which in the Appalachians consisted of a thickness of 40,000 feet of strata, and in the Alps of 50,000 feet.

Geo-anticlinals.—The next series of operations contributing to the formation of the mountain-chain is the action of lateral or

tangential thrusts whereby the great thickened masses forming the geosynclinal are folded and fractured, and the sundered masses being forced one over the other—in the way we see so strikingly exemplified, not only in mountain-chains like the Alps and Himalayas, but in districts like the Highlands of Scotland and Scandinavia where great mountains have once existed.

It is a most striking and significant circumstance that the great movements which gave rise to the folding and elevation of the strata forming the Alps and Himalayas took place at the time when the sands and clays of the northern part of the Isle of Wight and the New Forest were being accumulated! Strata of the same age as the London Clay, the Barton Clay, and the Bracklesham beds are found in the Alps and Himalayas at heights of 10,000 and 16,000 feet respectively. Indeed it is probable that the monoclinal fold which affects the strata of the Isle of Wight with the anticlinal of the Weald and the synclinal of the London Basin are but portions of that series of earth-movements which, in Oligocene times and subsequently, affected the whole of the rocks of Southern Europe and Asia, and gave rise to the elevation of the Alps and Himalayas.

Denudation.—The third great series of operations concerned in the formation of mountain-ranges consists in the sculpturing action of denudation which has gone on, to a great extent, side by side with the work of folding, crumpling, fracturing and elevation. While it is true that all the actual forms of the rock-masses constituting a mountain-chain are due to the sculpturing action of denuding forces, it must not be forgotten how much that action has been controlled and modified by the great internal movements and changes within the earth's crust. Such, very briefly sketched, seems to have been the general succession of events in the formation of typical mountain-chains—though of course local conditions have often modified the sequence in particular cases. That the metamorphism of rock-masses has been effected while they have been buried at great depths, so as to have been exposed to a moderately high temperature and at the same time subjected to intense dynamical action, there is every ground for believing. But in the nature of the case, the actual processes by which particular rock-masses of this class have been formed must always be difficult to determine.

It must not be supposed from what has been said that the folding and fracturing of rock-masses is always attended with metamorphism and the production of foliation. While it is certainly true that all highly altered rocks exhibit evidence of having been subjected to great movements and tangential strains, the converse is by no means true. Strata of all ages, from the Carboniferous upwards, are found in the Alps caught up in complicated folds, and themselves bent and puckered in the most remarkable manner, yet retaining their mineralogical characters, and exhibiting their fossils almost unaltered. Doubtless the depth at which a rock-mass lies, and the consequent temperature which it attains while it is being subjected to folding and fracture, and other surrounding circumstances, may have much to do with determining whether the process of recrystallisation shall be set up in the mass, and foliation thus produced, or not. Mr. Mallet has suggested that the mechanical work of rock-crushing may be actually converted into heat and chemical action, and, if this be the case, then the time in which the operation is effected would

determine whether the results of the action would accumulate to produce great results or be gradually dissipated.

An excellent account of modern views concerning the origin of mountain-chains of different types will be found in Dana's 'Manual of Geology' (5th edition, 1895), pp. 345–396. The student would also do well to consult the Memoir by Mr. Bailey Willis 'On the Mechanics of Mountain Structure as displayed by the Appalachian ranges,' published in the 13th Report of the U. S. Geological Survey.

CHAPTER XLI

ORE-DEPOSITS AND THEIR ORIGIN

Ore-deposits usually formed by Hypogene action—Classification of Ore-deposits—Origination of Metalliferous Veins in fissures—Different ages of the formation and infilling of Veins—Proofs of successive opening and refilling of Veins—Comb-structure in Veins—Irregularities in width of Veins—Chemical Deposition in Veins—Supposed relative ages of different metals.

Hypogene origin of most Ore-deposits.—The various deposits in which the ores of the metals employed in the arts are found are of great practical value to mankind, and the study of their mode of occurrence and origin is of the highest theoretical interest to geologists. Some masses of the ores of iron and manganese, like the lake-ores of Sweden (see p. 48), are evidently of aqueous origin, and a few deposits of volatile compounds, like the sulphides of arsenic and mercury, are seen to be deposited around volcanic vents. But the great majority of the ore-deposits, which are of such importance to mankind, are evidently of deep-seated or hypogene origin, and are closely connected with plutonic and metamorphic rock-masses. Some ores, like the ironstone of Cleveland and the Kupferschiefer of Thuringia, have been produced during the consolidation and alteration of stratified deposits. The larger part of the precious and other metals used by man is obtained, however, from veins and analogous deposits, the nature and origin of which we must proceed to consider.

Different kinds of mineral veins.—The mineral veins with which we are most familiarly acquainted are those of quartz and calcite, which are often observed to form lenticular masses of limited extent traversing both hypogene strata and fossiliferous rocks. Such veins appear to have once been chinks or small cavities, caused by the contraction or movement of the rock-masses which they traverse. Siliceous, calcareous, and

occasionally metallic matters sometimes find their way into such empty spaces by infiltration from the surrounding rocks. Carried by water or steam, metallic compounds may have permeated the mass until they reached those receptacles formed by shrinkage, and thus gave rise to that irregular assemblage of veins called by the Germans a 'Stockwerk,' in allusion to the different floors on which the mining operations are in such cases carried on.

The late J. A. Phillips showed that in Nevada, hot springs rise to the surface and deposit silica, with metallic ores, including gold and the compounds of mercury which incrust the walls of the fissures.

The more ordinary or regular veins, usually highly inclined or vertical, have evidently been fissures produced by similar mechanical actions. They traverse all kinds of rocks, both hypogene and fossiliferous, and extend downwards to indefinite or unknown depths. We may assume that they correspond with such rents as we see caused in rocks by movement and faulting. Metalliferous veins are occasionally a few inches wide, but more commonly 3 or 4 feet, and some are as much as 150 feet in width. They hold their course continuously in a certain prevailing direction for a short distance or for miles or leagues, passing through rocks varying in mineral composition.

Metalliferous veins were fissures.—There are proofs in almost every mining district of a succession of faults, by which the opposite walls of rents, now the receptacles of metallic substances, have suffered displacement. Thus, for example, suppose *a a*, fig. 728, p. 570, to be a tin-lode in Cornwall, the term *lode* being applied to veins containing metallic ores. This lode, running east and west, is a yard wide, and is shifted by a copper lode (*b b*), of similar width. The first fissure (*a a*) has been filled with various materials, partly of chemical origin, such as quartz, fluor-spar, tinstone, copper-glance, arsenical pyrites, native bismuth, and nickeliferous pyrites, and partly of mechanical origin, comprising clay and angular fragments or detritus of the intersected rocks. The successive deposits of spars and ores are, in some places, parallel to the vertical sides or walls of the vein, being divided from each other by alternating layers of clay, or other earthy matter. Occasionally, however, the metallic ores are disseminated in detached masses among the sparry minerals or vein-stones.

It is clear that, after the gradual introduction of the tinstone and other substances, the second rent (*b b*) was produced by another fracture accompanied by a displacement of the rocks along the plane of *b b*. This new opening was then filled with minerals, some of them resembling those in *a a*, as fluor-spar and quartz; others different, the copper ore being plentiful, and the tin ore wanting or very scarce. We must next suppose a third movement to occur,

breaking asunder all the rocks along the line *c c*, fig. 729 ; the fissure, in this instance, being only six inches wide, and simply filled with clay, derived, probably, from the friction of the walls of the rent, or

Fig. 728.

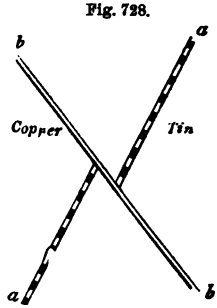


Fig. 729.

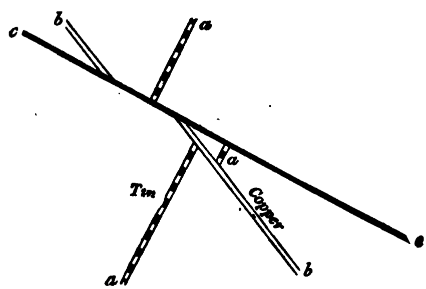
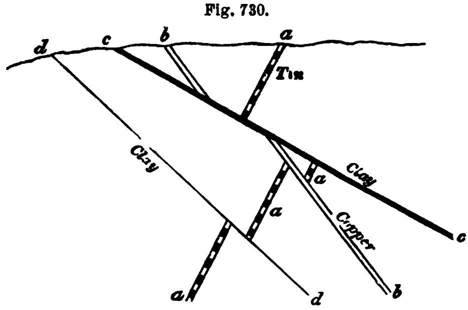


Fig. 730.



Vertical sections of the mine of Huel Peeer, vRedruth, Cornwall.

partly, perhaps, washed in from above. This new movement has displaced the rock in such a manner as to interrupt the continuity of the copper vein (*b b*), and, at the same time, to shift or heave

laterally in the same direction a portion of the tin vein which had not previously been broken.

Again, in fig. 730, we see evidence of a fourth fissure (*d d*), also filled with clay, which has cut through the tin vein (*a a*), and has lifted it slightly upwards towards the south. The various changes here represented are not ideal, but are exhibited in a section obtained in working an old Cornish mine, long since abandoned, in the parish of Redruth, called Huel Peever, and described both by Williams and Carne. The principal movement here referred to, or that of *c c*, fig. 729, extends through a space of no less than 84 feet; but in this, as in the case of the other three, it will be seen that the outline of the country above, *d*, *c*, *b*, *a*, &c., or the geographical features of Cornwall, are not affected by any of the dislocations, a powerful denuding force having clearly been exerted subsequently to all the faults. It is commonly said in Cornwall that there are eight distinct systems of veins, which can in like manner be referred to as many successive movements or fractures; and the German miners of the Hartz Mountains speak also of eight systems of veins, referable to as many periods.

Besides the proofs of mechanical action already explained, the opposite walls of veins are often beautifully polished, as if glazed, and are not unfrequently striated or scored with parallel furrows and ridges (slickensides), such as would be produced by the continued rubbing together of surfaces of unequal hardness.

In some of the veins in the Mountain limestone of Derbyshire containing galena, the vein-stuff, which is nearly compact, is occasionally traversed by what may be called a vertical crack passing down the middle of the vein. The two faces in contact are slickensides, well polished and fluted, and sometimes covered by a thin coating of lead-ore. When one side of the vein-stuff is removed, the other side cracks, especially if small holes be made in it, and fragments fly off with loud explosions (owing to the relief from strain), and continue to do so for some days. The miner, availing himself of this circumstance, makes with his pick small holes about six inches apart and 4 inches deep, and on his return in a few hours finds every part ready broken to his hand.

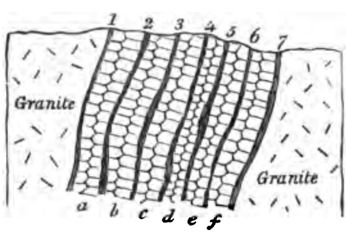
That a great many veins communicated originally with the surface of the country above, or with the bed of the sea, is proved by the occurrence of well-rounded pebbles in them, agreeing with those in superficial alluvia, as in Auvergne and Saxony. Marine fossil shells, also, have been found at great depths, having possibly been engulfed during submarine earthquakes. Thus, the late Charles Moore described lead-veins traversing the Carboniferous limestone of the Mendips in Somerset, which at the time they were filled must have been in communication with the Liassic sea, for he found Lias fossils in them. In Cornwall, Carne described true pebbles of quartz and slate as occurring in a tin lode of the Relistran Mine, at the depth of 600 feet below the surface. They were cemented by tinstone and copper pyrites, and were traced over a space more than twelve feet long and as many wide. When different sets or systems of veins occur in the same country, those which are supposed to be of contemporaneous origin, and which are filled with the same kind of ores, often maintain a general parallelism of direction. Thus, for example, both the tin and copper veins in Cornwall run nearly

east and west, while the lead-veins run north and south; but there is no general law of direction common to different mining districts. The parallelism of the veins is another reason for regarding them as ordinary fissures, for we observe that faults and volcanic dykes, admitted by all to be masses of melted matter which have filled rents, are often parallel.

Fracture, Reopening, and Successive Formation of Veins.—Assuming, then, that veins are simply fissures in which chemical and mechanical deposits have accumulated, we may next consider the proofs of their having been filled gradually and often during successive enlargements.

Werner observed, in a vein near Gersdorff, in Saxony, no less than thirteen bands of different minerals, arranged with the utmost regularity on each side of the central layer. This layer was formed of two plates of calcareous spar, which had evidently lined the opposite walls of a vertical cavity. The thirteen beds followed each other in corresponding order, consisting of fluor-spar, heavy spar, galena, &c. In these cases the central mass has been last formed, and the two plates which coat the walls of the rent on each side are the oldest of all. If they consist of crystalline precipitates, they may be explained by supposing the fissure to have remained unaltered in its dimensions, while a series of changes occurred in the nature of the solutions which rose up from below; but such a mode of deposition, in the case of many successive and parallel layers, appears to be exceptional.

Fig. 731.



Copper lode, near Redruth, enlarged at successive periods.

If a veinstone consists of crystalline matter, the points of the crystals are always turned inwards, or towards the centre of the vein; in other words, they point in the direction where there was space for the development of the crystals. Thus each new layer receives the impression of the crystals of the preceding layer, and imprints its crystals on the one which follows, until at length the whole of the vein is filled; the two layers which meet dovetail the points of their crystals the one into the other. But in Cornwall, some lodes occur where the vertical plates, *combs*, as they are there called, exhibit crystals so dovetailed as to prove that the same fissure has been often enlarged. De la Beche described the following curious and instructive example (fig. 731), from a copper-mine in granite, near Redruth. Each of the plates or combs (*a, b, c, d, e, f*) is doubled, having the points of their crystals turned inwards along the axis of the comb. The sides or walls (2, 3, 4, 5, and 6) are parted by a thin covering of ochreous clay, so that each comb is readily separable from another by a moderate blow of the hammer. The breadth of each represents the whole width of the fissure at six successive periods, and the outer walls of the vein, where the first narrow rent was formed, consisted of the granitic surfaces 1 and 7.

A somewhat analogous interpretation is applicable to many other cases, where clay, sand, or angular detritus alternates with ores and veinstones. Thus, we may imagine the sides of a fissure to be incrusted with siliceous matter after the manner observed by Von Buch in Lancerote. He noticed that the walls of a volcanic crater formed in 1731 were traversed by an open rent in which hot vapours had deposited hydrous silica, the incrustation nearly extending to the middle. Such a vein may subsequently be filled with clay or sand, and afterwards reopened, the new rent dividing the argillaceous deposit, and allowing a quantity of rubbish to fall down. Various ores and spars may then be precipitated from aqueous solutions percolating among the interstices of this heterogeneous mass.

That such changes have taken place repeatedly is demonstrated by the occurrence of occasional cross-veins, implying the oblique fracture of previously formed chemical and mechanical deposits. Thus, for example, M. Fournet, in his description of some mines in Auvergne, worked under his superintendence, observes that the granite of that country was first penetrated by veins of massive granite and then dislocated, so that open rents crossed both the granite and the granitic veins. Into such openings, quartz, accompanied by iron pyrites and arsenical pyrites, was introduced. Another movement then burst open the rocks along the old line of fracture, and the first set of deposits was cracked and often shattered, so that the new rent was filled not only with angular fragments of the adjoining rocks, but with pieces of the older veinstones. Polished and striated surfaces on the sides or in the contents of the vein also attest the reality of these movements. A new period of repose then ensued, during which various sulphides were introduced, together with chalcedonic silica of the variety known as hornstone, by which angular fragments of the older quartz before mentioned were cemented into a breccia. This period was followed by other dilatations of the same veins, and the introduction of new sets of mineral deposits, as well as of pebbles of the basaltic lavas of Auvergne, derived from superficial alluvia, probably of Miocene or even older Pliocene date. Such repeated enlargement and reopening of veins might have been anticipated, if we adopt the theory of fissures, and reflect how few of them have ever been sealed up entirely, and that a country with fissures only partially filled must naturally offer much feebler resistance along the old lines of fracture than anywhere else.

Cause of alternate contraction and swelling in veins.—A large proportion of metalliferous veins have their opposite walls nearly parallel, and sometimes over a wide extent of country. But many lodes in Cornwall and elsewhere are extremely variable in size, being 1 or 2 inches in one part, and then 8 or 10 feet in another, at the distance of a few fathoms, and then again narrowing as before. Such alternate swelling and contraction are so often characteristic as to require explanation. The walls of fissures in general, as De la Beche pointed out, are rarely perfect planes throughout their entire course, nor could we well expect them to be so, since they commonly pass through rocks of unequal hardness and different mineral composition. If, therefore, the opposite sides of such irregular fissures slide upon each other, that is to say, if there be a fault, as in the

case of so many mineral veins, the parallelism of the opposite walls is at once entirely destroyed, as will be readily seen by studying the annexed diagrams.

Let *a*, *b*, fig. 732, be a line of fracture traversing a rock, and let *a*, *b*, fig. 733, represent the same line. Now, if we cut in two a piece of paper representing this line, and then move the lower portion of this cut paper sideways from *a* to *a*, taking care that the

Fig. 732.

Fig. 733.

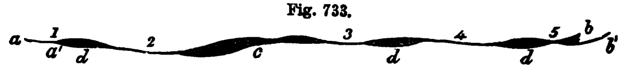
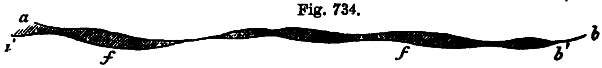
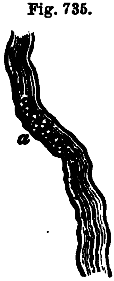


Fig. 734.



two pieces of paper still touch each other at the points 1, 2, 3, 4, 5, we obtain an irregular aperture at *c*, and isolated cavities *d d d*, and when we compare such figures with Nature we find that, with certain modifications, they represent the interior of faults and mineral veins. If we move the lower part of the paper towards the left about the same distance that it was previously moved to the right, we obtain considerable variation in the cavity so produced, two long irregular open spaces, *f f*, fig. 734, being then formed. This will serve to show to what slight circumstances considerable variations in the character of the openings between unevenly fractured surfaces may be due, such surfaces being moved upon each other, so as to have numerous points of contact.

Fig. 735.



Most lodes are perpendicular to the horizon, or nearly so; but some of them have a considerable inclination or 'hade,' as it is termed, the angles of dip being very various. The course of a vein is frequently very straight; but, if tortuous, it is found to be choked up with clay, stones, and pebbles, at points where it departs most widely from verticality. Hence at places, such as *a*, fig. 735, the miner complains that the ores are 'nipped,' or greatly reduced in quantity, the space for their free deposition having been interfered with in consequence of the preoccupancy of the lode by earthy materials. When lodes are many fathoms wide, they are usually filled for the most part with earthy matter and fragments of rock, through which the ores are disseminated. The metallic substances frequently coat or encircle detached pieces of rock, which our miners call 'horses' or 'riders.' That we should find some mineral veins which split into branches is also natural, for we observe the same in regard to open fissures.

Chemical deposits in veins.—If we now turn from the mechanical to the chemical agencies which have been instrumental in the production of mineral veins, it may be remarked that those

parts of fissures which were choked up with the ruins of fractured rocks must always have been filled with water; and almost every vein has probably been the channel by which hot springs, so common in countries of volcanoes and earthquakes, have made their way to the surface. For we know that the rents in which ores abound extend downwards to vast depths, where the temperature of the interior of the earth is more elevated. We also know that mineral veins are most metalliferous near the contact of plutonic and stratified formations, especially where the former send veins into the latter, a circumstance which indicates an original proximity of veins at their inferior extremity to igneous and heated rocks. It is, moreover, acknowledged that even those mineral and thermal springs, which, in the present state of the globe, are far from volcanoes, are nevertheless observed to burst out along great lines of upheaval and dislocation of rocks. It is also ascertained that, among the substances with which hot springs are impregnated, such as are volatile also occur in the gaseous emanations of volcanoes. The whole of these are also among the constituents of the minerals most usually found in veins, such as quartz, calcite, fluor-spar, the metallic sulphides, heavy-spar, brown-spar, and the oxides of iron. We may add that, if veins have been filled with gaseous emanations from masses of melted matter, slowly cooling in the subterranean regions, the contraction of such masses as they pass from a plastic to a solid state would, according to the experiments of Deville on granite (a rock which may be taken as a type), produce a reduction in volume amounting to 10 per cent. The slow crystallisation, therefore, of such plutonic rocks supplies us with a force not only capable of rending open the incumbent rocks by causing a failure of support, but also of giving rise to fissures whenever one portion of the earth's crust subsides slowly while another contiguous to it happens to rest on a different foundation, so as to remain unmoved.

Although we are led to infer, from the foregoing reasoning, that there has often been an intimate connection between metalliferous veins and hot springs holding mineral matter in solution, yet we must not on that account expect that the contents of hot springs and mineral veins would be identical. On the contrary, M. E. de Beaumont has judiciously observed that we ought to find in veins those substances which, being least soluble, are not discharged by hot springs—or that class of simple and compound bodies which the thermal waters ascending from below would first precipitate on the walls of a fissure, as soon as their temperature began slightly to diminish. The higher they mount towards the surface, the more will they cool till they acquire the average temperature of springs, being in that case chiefly charged with the most soluble substances, such as salts of the alkalies, soda and potash. These are seldom met with in veins, although they enter so largely into the composition of granitic rocks.

To a certain extent, therefore, the arrangement and distribution of metallic matter in veins may be referred to ordinary chemical action, or to those variations in temperature which waters holding the ores in solution must undergo as they rise upwards from great depths in the earth. But there are other phenomena which do not admit of the same simple explanation. Thus, for example, in

Derbyshire, veins containing ores of lead, zinc, and copper, but chiefly lead, traverse alternate beds of limestone and basalt. The ore is plentiful where the walls of the rent consist of limestone, but is reduced to a mere string when they are formed of basalt, or 'toad-stone,' as it is called provincially. Not that the original fissure is narrower where the basalt occurs, but because more of the space is there filled with veinstones, and the waters at such points have not parted so freely with their metallic contents.

Lodes in Cornwall are very much influenced in their metallic riches by the nature of the rock which they traverse, and they often change in this respect very suddenly, in passing from one rock to another. Thus many lodes which yield abundance of ore in granite are unproductive in clay-slate, or killas, and *vice versâ.*

Theories as to the Origin of Ore-deposits.—In recent years the studies carried on in the Western States of North America, in South America, South Africa, and Australia, have shown that ore-deposits are much more varied in character than was supposed by the students of mineral veins in Saxony and Cornwall. It has been found necessary, in order to account for some of these deposits, to modify and extend the theories which were thought sufficient to explain the origin of ordinary veins.

Professor Clement Le Neve Foster classifies all ore-deposits under the following heads :—

I. Tabular or sheet-like, including { A. Beds or stratified deposits. B. Veins.

II. Masses including . . { A. Necks or pipes (like the diamond rocks of South Africa). B. Stockworks, or 'Network-deposits.' C. Various irregular masses of doubtful origin.

The origin of veins and other ore-deposits has, according to the same authority, been variously referred to the following causes :—

1. Fracture and motion with mechanical filling.
2. Fracture and injection of molten matter.
3. Fracture and deposition from solutions, { A. from above. B. from below. C. from the sides.
4. Fracture and sublimation, or deposition from gases.

Very much still remains to be done in the study of ore-deposits, before we can hope to supply reasonable explanations of many of the remarkable occurrences of metallic ores within the earth's crust.

For further information on the subject of Ore-deposits the student is recommended to consult J. A. Phillips's 'Ore-deposits,' 1884, and the various monographs of the U. S. Geological Survey on the Comstock Lode, the Leadville and the Eureka deposits, and that on the Quicksilver deposits of the Pacific Slope.

CHAPTER XLII

ON THE DIFFERENT AGES OF METAMORPHIC ROCKS, MOUNTAIN-CHAINS AND ORE-DEPOSITS

How the age of Metamorphic Rocks is determined—Period of original formation—Period of Metamorphism—Disturbed condition of Metamorphic Rocks—Age of Rocks formed by Contact-metamorphism—Similarity of Rocks formed by Contact-metamorphism to those produced by Regional metamorphism—Difficulty of determining age of Rocks formed by latter process—Metamorphic Rocks of the Alps—Supposed Tertiary age—Metamorphic Rocks of Mesozoic Age—Metamorphic Rocks of Newer Palæozoic Age—Metamorphic Rocks of Older Palæozoic Age—Metamorphic Rocks of Pre-Cambrian Age—Uniformity of characters in Metamorphic Rocks of all ages—Supposed parallelism of Mountain-chains formed during different periods—Mountain-chains of Tertiary, Mesozoic, Palæozoic, and Archæan Ages—Ages of Ore-deposits—Supposed relative ages of different metals—Origin and age of Gold-deposits.

Tests of the age of Metamorphic Rocks.—We have seen in the earlier chapters of this work that, by means of stratigraphical and palæontological evidence, a chronological sequence can be traced among the various deposits of *aqueous* origin forming the earth's crust. In the case of the rocks of *volcanic* origin, the relations which they exhibit to stratified masses, and the fossils which they occasionally contain, enable us—though often with some doubt and hesitation—to refer the various lavas and tuffs to portions of the same sequence. But, when we pass from the epigene to the hypogene rocks, the task of making out a chronological succession among the intrusive or *plutonic* masses has been shown to be beset with far more serious difficulties, and the conclusions arrived at consequently liable to much greater uncertainty.

It is in the case of the metamorphic rocks, however, that the geologist experiences the greatest amount of difficulty in determining their relative ages. Not only do we find, as in the case of the plutonic rocks, that the younger hypogene rocks are but rarely exposed by denudation at the surface, but the fact that extreme regional metamorphism is in almost all cases connected with great terrestrial movements, prepares us for encountering repeated foldings, complicated inversions, and violent displacements of rock-masses; and under these circumstances—all traces of fossils having necessarily been destroyed in the recrystallised materials—geologists often find it extremely difficult, if not quite impossible, to arrive at definite conclusions concerning their original sequence.

Disturbed condition of Metamorphic Rocks.—According to the theory of metamorphism adopted in this work, the metamorphic and foliated rocks have been deposited during one geological period, and have become crystalline at another and later period. We can rarely hope to define with exactness the date of each of these periods, the fossils having been destroyed by the process of crystallisation, while mineral characters are identical in rocks of very different ages.

When we come to study the metamorphic rocks in detail, moreover, we find abundant evidence that, before or during metamorphism, rocks of the most varied geological age may have become infolded with or faulted against one another; and further, that the work of metamorphism, resulting in recrystallisation and foliation, has not been accomplished in a single period, but has probably been repeated again and again at different geological epochs. Hence we must not be surprised to find that, with respect to many of these greatly disturbed and much altered rock-masses, the task of unravelling their complicated history has proved an insuperable one, and geologists have been unable to arrive at anything like agreement concerning all the difficult problems presented to them by the metamorphic rocks.

Relative ages of Rocks formed by Contact-metamorphism.—The simplest cases are undoubtedly those presented to us in the study of contact-metamorphism. Within a distance of two miles or less, we may often find a rock crowded with fossils undergoing progressive changes, as we approach the igneous intrusion, until at last—as new crystals of minerals multiply in the mass, and all traces of organisms are finally obliterated—the rock may become highly crystalline, and even perfectly foliated. In many cases the passage from the fossiliferous to the crystalline rock can be followed in such obvious gradations, that no doubt about the geological age of the material out of which the slate, schist, or gneissose rock has been formed can possibly exist. If we are able also to determine the period of the intrusion of the igneous mass around which this contact-metamorphism is developed, we have then before us all the data necessary for settling the main facts concerning the chronology of a metamorphic rock.

That this metamorphic process is going on at the present day, around great igneous intrusions, we have conclusive evidence in the fragments thrown from the vents of Vesuvius and other volcanoes. These 'ejected blocks' have evidently been torn from the rocks through which the igneous materials are forcing their way to the surface; they sometimes contain fossils which can be distinctly recognised, but at other times exhibit the signs

of more and more complete recrystallisation, not unfrequently accompanied with the development of a distinctly foliated structure.

Stratified and fossiliferous rocks belonging to every geological period, from the Tertiary downwards, are found altered in this way by igneous intrusions of every date, so that in the case of the rocks produced by contact-metamorphism the continuity and uniformity of metamorphic processes, from the earliest periods of the geological history down to the present day do not admit of doubt.

Analogy between Rocks formed by Contact- and Regional-metamorphism respectively.—Recent petrographical researches have undoubtedly tended towards the conclusion that there is a much closer analogy between the rocks produced by contact-metamorphism and those which are the result of regional metamorphism than was at one time supposed. In the zones surrounding great granitic bosses like those of Galloway, so well described by Miss I. Gardiner, we find mica-schists rich in garnets and other accessory minerals, which have undoubtedly been formed by the alteration of Ordovician greywackés and flagstones; yet these nevertheless are not distinguishable by any important characters from the mica-schists, intercalated with gneisses, and similar rocks forming portions of districts which have been subjected to regional metamorphism. On the other hand, minerals at one time supposed to be especially characteristic of the rocks formed by contact metamorphism, such as andalusite, sillimanite, kyanite, staurolite, &c., have now been found to be much more widely distributed and to form important constituents not only of the schists but also of the granitic gneisses of districts where the rocks have resulted from regional metamorphism.

Relative ages of Rocks produced by Regional metamorphism.—In the face of the almost total absence of palæontological evidence, and the obliteration of all structural characters by recrystallisation and foliation, the task of defining the age of the great masses of hypogene and highly altered rocks is one surrounded by great and indeed almost insuperable difficulties. Rocks affected by slaty cleavage are certainly known belonging to every geological epoch; the slates of Glaris contain fish of Eocene age; and other cleaved rocks might be adduced that can be referred to almost every division of the Mesozoic and Palæozoic epochs. In many cases, too, these 'clay-slates' are found passing insensibly into true 'phyllites,' in which a considerable amount of chemical change has taken place in addition to the mechanical effects of pressure.

In Norway, as Professor Reusch has so well shown, there are undoubted phyllites, approaching to true schists in structure, which contain trilobites, brachiopoda, and corals of Silurian age. Scarcely less altered rocks with Devonian fossils occur in Devonshire. It would be unreasonable to expect that rocks which can only have undergone the extremes of metamorphic change by being buried to most profound depths in the earth's crust should be *frequently* exhibited at the earth's surface by denudation, unless they were of great geological antiquity. When so exposed, it is often not possible to assert with confidence that they are really integral parts of the great masses among which they now lie, and have not been caught up and rolled out among rocks of far greater antiquity.

Some geologists of authority, indeed, have been led to affirm that the great and wide-spread masses of gneiss and schist covering vast areas of the earth's surface have so little in common with the smaller masses that can be proved to have been formed by contact metamorphism or by the metamorphism of sedimentary and igneous materials, that we must, in all cases, infer for these very highly crystalline masses a pre-Palæozoic age, and probably an origin different from that of any rocks formed since the commencement of the geological record.

But it must be remembered that, just as it has been found impossible by petrologists to point out any fundamental distinctions between the rocks formed by contact-metamorphism and those resulting from more wide-spread action at greater depths upon ancient sediments, lavas and tuffs, so the difference between the characters of the granitic gneisses and true schists on the one hand, and the phyllites and similar rocks on the other, is, to say the least, often shadowy and indefinite. It is not unreasonable to suppose that a more deeply seated action, a higher temperature, or the more intense or more prolonged operation of dynamic agencies, may lead to changes the result of which is seen in the most perfectly recrystallised metamorphic rocks; for these changes differ in degree rather than in kind from those the effects of which we can so clearly follow.

On the other hand, it would be rash to affirm that among the widely spread and highly crystalline rocks that underlie all the rocks, the sedimentary or volcanic origin of which can be clearly demonstrated, there may not be found some of which the origin is different from that of the undoubted metamorphic rocks —some relics of a primæval condition of the earth, when rock-masses may have been formed under conditions essentially different from those which now prevail in the earth's crust. As,

however, the metamorphic theory—admitting such extension of it as is reasonable with increasing temperature and pressure—seems fully adequate to the explanation of the origin of these highly crystalline rocks, the *onus* of proof that other conditions prevailed during their formation rests with those who make the assertion.

Examples of Rocks formed by Regional metamorphism which are of different Geological ages.—Owing to the great foldings and faulting to which most metamorphic rocks have been subjected, great differences of opinion have arisen concerning the relative ages of many metamorphic masses. The following statements concerning certain cases, therefore, must be taken as indicating probabilities rather than actually demonstrated conclusions.

Metamorphic Rocks of the Alps possibly of Tertiary age.—The existence of rocks in mountain masses of Palæozoic, Secondary, and even of Eocene age, metamorphosed into crystalline schists, has been asserted over and over again in the Alps. The late Professor Favre, of Geneva, to whom we owe so much correct knowledge regarding the Alps, traced the origin of Mont Blanc from a time when palæozoic rocks of Carboniferous age, with their beds of coal and plant-remains, were deposited upon a partially submerged region of gneiss and crystalline schists. Many of the strata contain the denuded remains of these schists. Some disturbance occurred, and the secondary rocks were laid down during subsidence, and finally the Nummulitic series of overlying sandstones. Then came the great movement of mountain-making, and the strata and schists were curved, folded, faulted, inverted, and thus schists were forced above the reversed fossiliferous series. The products of the wear and tear of the mountain-mass collected in the form of strata of gravels and clays on its flanks, and at last the final tangential movements came, which added to the complication by inverting the last-made strata on the flanks of the Alps, so that they appear to dip underneath the Nummulitic group.

A very remarkable paper on the geology of the Alps, by Murchison, in 1848, refers to the Pass of Martinsloch, in Glarus, 8,000 feet above sea-level. In this locality, Nummulitic beds dipping S.S.E., at a high angle, are regularly overlaid by the succeeding Flysch sandstone, resting unconformably, and in a nearly horizontal attitude, upon the edges of which are 150 feet of hard Jurassic limestone, overlain in its turn by *talcose* and *micaceous schists*, which were regarded by Escher as similar to those which underlie these limestones in the valley below. The mass of Flysch appears nearly to dip beneath these limestones, which in their turn are overlain by Neocomian and Cretaceous strata. The superposition of the schists may not have been original, but may have been brought about by fracture and displacement along an anticlinal. Similar great inversions are seen in the Valley of Chamounix, where secondary limestones dip at a high angle towards Mont Blanc, and plunge beneath its crystalline schists.

In one of the sections described by Studer in the highest of the Bernese Alps, namely, in the Roththal, a valley bordering the line of perpetual snow on the northern side of the Jungfrau, there occurs a

mass of gneiss 1,000 feet thick and 15,000 feet long, which is seen not only resting upon, but also again covered by strata containing oolitic fossils. These anomalous appearances may partly be explained by supposing great solid wedges of intrusive gneiss to have been forced in laterally between strata to which they are found to be in many sections unconformable (see fig. 727, p. 565). The superposition also of the gneiss to the oolite may be due to a reversal of the original position of the beds in a region where the contortions have been on so stupendous a scale.

Most living Swiss geologists, like Heim, Baltzar, and Renevier, believe that some of the metamorphic rocks of the Alpine chain represent Newer Palæozoic, Mesozoic, and even Eocene rocks, which have undergone great metamorphism. This conclusion is, however, disputed by Professor Bonney and some other geologists, who explain the position of younger rocks among the schistose masses of the Alpine chain by asserting that they are due in all cases to folding and faulting of the rocks.

Metamorphic Sedimentary Rocks of Mesozoic Age.—Neumayr and other geologists have described masses of chlorite-schist, mica-schist, and gneiss in Greece, as alternating with beds of more or less altered limestone which, in some cases, contain obscure but undoubted traces of fossils. The rocks from which these metamorphic fossils were formed are supposed to be the Hippurite limestones and other Cretaceous strata, and the metamorphism must have occurred in post-Cretaceous, if not Tertiary times.

In the coast ranges of the Pacific Slope of California, Dr. Becker and the officers of the United States Geological Survey have described granulitic rocks, glaucophane schists, phthanites (silicified limestones) and serpentinous rocks as being formed from stratified masses of undoubted Neocomian age. Other strata of Jurassic age in California are, according to Whitney, found altered into clay-slate, talcose slate, and serpentinous rocks.

Northern Apennines, Carrara.—The celebrated marble of Carrara, used in sculpture, was once regarded as a type of primitive limestone. The absence of fossils, its mineral texture and composition, and its passage downwards into talc-schist and garnetiferous mica-schist, gave it the appearance of a rock of great age, especially as underlying gneisses, penetrated by granite veins, are believed to graduate into the schists. The variety of opinions regarding the age of this limestone which have been published by competent authorities should warn the student against geological dogmatism in this difficult question of the age of metamorphic rocks. Most geologists believe that the marble is an altered Triassic or Jurassic limestone, and that the underlying schists are altered plutonic rocks of secondary age.

Examples of Metamorphic Rocks of Newer Palæozoic age.—Besides the cases of altered Carboniferous rocks converted into schists which have been asserted by many geologists to occur in the Alps, we have in the district of the Taunus in Central Germany, as pointed out by Lossen, Lower Devonian strata altered into various clay slates and spotted slates, with quartzites, phyllites, mica-schist, and even sericite-gneiss. Although some authors assert these altered strata to be of Older Palæozoic age, yet no good grounds have been adduced for assigning them to an earlier geological period than that to which they were referred by Lossen.

In the Ardennes, Dumont and Renard have shown that a series of quartzites and phyllites graduating into highly crystalline rocks containing hornblende, mica, garnet, sphene, graphite, and many other minerals, are really the altered representatives of Devonian strata. In the metamorphosed rocks Sandberger has been able to detect two undoubted forms of Devonian Brachiopoda.

Metamorphic Rocks of Older Palæozoic age.—The most interesting examples to the British geologist of rocks of this age are those found in the Highlands of Scotland. We have already seen that, pushed over the Lewisian gneisses and the Torridonian sandstones, and the Cambrian limestones, quartzites, and shales by great reversed faults (thrusts), we find the great masses of gneiss (Caledonian of Callaway, and Dalradian of Geikie), which cover so large a portion of Scotland, north of the valleys of the Forth and Clyde (see fig. 631, p. 436). These gneisses and schists have a very different aspect from the Lewisian or fundamental gneiss, and, as long ago pointed out by Nicol, graduate when traced southwards towards the central valley of Scotland into slaty rocks, in which, however, fossils have not yet been found. The officers of the Geological Survey are led to conclude that these 'younger schists and gneisses' of the Highlands are really the altered representatives of Torridonian, Cambrian, and Ordovician strata and of igneous intrusions in them, and that the metamorphism of these rocks was effected in Silurian times.

In Scandinavia, Cambrian, Ordovician, and even Silurian strata are similarly found converted into quartzites, phyllites, and even true schists and gneisses, the clastic origin of the rocks being betrayed, however, by the presence of pebbles, and even in some cases by traces of fossils.

In the Green Mountains of New England, Dana and others have described schists and limestones, which have been formed by the metamorphism of the Ordovician strata of the district.

Metamorphic Rocks of pre-Cambrian age.—Many of the schists and gneisses of the globe are undoubtedly older than the oldest-known fossiliferous rocks, for these latter not only overlie them, but contain fragments derived from them. As we have already pointed out, these undoubtedly pre-Cambrian gneisses and schists have not been shown to exhibit any characters by which they can be clearly distinguished from rocks of the same class belonging to later periods.

Order of Succession in Metamorphic Rocks.—It has been remarked that, as the hypogene rocks, both stratified and unstratified, crystallised originally at a certain depth beneath the surface, they must always—in order to be upraised and exposed at the surface by denudation—be of considerable antiquity, relatively to a large portion of the fossiliferous and volcanic rocks. Whether they were forming during all the geological periods is a debated question; but before any of them can become visible, they must be raised above the level of the sea, and the rocks which previously concealed them must have been removed by denudation. There is no universal and invariable order of superposition among metamorphic rocks, although a particular arrangement may prevail throughout districts of great extent.

If we investigate different mountain-chains, we find gneiss,

mica-schist, hornblende-schist, chlorite-schist, crystalline limestone, and other rocks, succeeding each other, and alternating with each other in every possible order. But the rule is that the thicker gneisses and most foliated schists are the oldest. It is, indeed, more common to meet with some variety of clay-slate forming the uppermost member of a metamorphic series than any other rock; but this fact by no means implies, as some have imagined, that all clay-slates were formed at the close of an imaginary period, when the deposition of the crystalline strata gave way to that of ordinary sedimentary deposits. Such clay-slates, in fact, are variable in composition, and sometimes alternate with fossiliferous strata, so that they may be said to belong almost equally to the sedimentary and metamorphic groups of rocks. It is probable that had they been subjected to more intense hypogene action, they would have been transformed according to their chemical composition into hornblende-slate, foliated chlorite-slate, scaly talcose-slate, mica-slate, or other phyllites, such as are usually associated with schist and gneiss.

Uniformity of mineral character in Hypogene Rocks.—It is true, as Humboldt has happily remarked, that when we pass to another hemisphere, we see new forms of animals and plants, and even new constellations in the heavens; but in the rocks we still recognise our old acquaintances—the same granite, the same gneiss, the same micaceous schist, quartz-rock, and the rest. There is certainly a great and striking general resemblance in the principal kinds of hypogene rocks, and of the regionally metamorphosed rocks in all countries, however different their ages. But when we remember how great has been the amount of recrystallisation of the materials, this uniformity of character may cease to surprise us. The more exact study of the oldest crystalline rocks of North America, South America, the Indian peninsula, Japan, &c., has already given grounds for believing that this uniformity is not so great as was at one time supposed; but that there are 'petrographical provinces' among the metamorphic, as well as among the igneous, rocks.

Age of Mountain-chains.—It was maintained by the French geologist, Elie de Beaumont, and his disciples that the mountain-chains of the globe appeared at particular periods of revolution in the earth's history, and that all the chains belonging to one period were parallel to one another. Somewhat similar views in a modified form have been advocated by MM. Bertrand, Prinz, and other geologists.

From a study of the position of rocks of known age in the different mountain chains, definite conclusions have been arrived at as to the geological period to which they must be referred. The Alps, the Jura, the Himalayas, and the Pyrenees all received their final elevation during the Tertiary era, from the Oligocene period onward; and during the same time the coast ranges of California and the Rocky Mountains were elevated; while the Sierra Nevada received its final uplift, according to Le Conte, in late Pliocene times. In South America, the Andes were elevated many thousands of feet during the Cainozoic era, while in the West India Islands we have clear evidence of the conversion of deep-sea deposits into high grounds since Miocene times. The close of the Mesozoic period was marked by the formation of the Laramide System, the Wasatch, and the Henry Mountains in North America, while earlier in the period

the Sierra Nevada and other chains were formed. At the close of the Palæozoic era, were formed the Appalachian chain in the east of the North American continent, and the Eureka Mountains of the great basin in the west. The mountains of Central Europe (Hercynian System) and the Urals are referred to the same period. During the Silurian epoch the great movements of the Scottish Highlands and of Scandinavia, and the formation of the Taconic Range in North America seem to have taken place. To various portions of the Archæan or pre-Cambrian must be referred many of the great denuded crystalline ridges of the globe, such as our own Fundamental gneiss, and the Laurentian masses of the North American continent.

Relative Ages of Mineral Veins.—From the facts already adduced (see p. 570 *et seq.*) we must admit that it is very probable that mineral veins are referable to many distinct periods of the earth's history, although it may be more difficult to determine the precise age of veins; because they have often remained open for ages, and because, as we have seen, the same fissure, after having been once filled, has frequently been reopened or enlarged. Sterry Hunt remarked that the process of filling veins has been going on from the earliest ages. We know of some which were formed before the Cambrian rocks were deposited, while others are still forming. It does not appear, however, that certain metals have been produced exclusively in earlier, others in more modern times—that tin, for example, is everywhere of higher antiquity than copper, copper than lead or silver, and all of them more ancient than gold.

In the first place, it is not true that veins in which tin abounds are the oldest lodes worked in Great Britain. The Geological Survey of Ireland has demonstrated that in Wexford, veins of copper and lead (the latter, as usual, being argentiferous) are much older than the tin of Cornwall. In each of the two countries a very similar series of geological changes has occurred at two distinct epochs—in Wexford, before the Devonian strata were deposited; in Cornwall, after the Carboniferous epoch. To begin with the Irish mining district: we have granite in Wexford, traversed by granite veins, which veins also intrude themselves into the Silurian strata, the same Silurian rocks as well as the veins having been denuded before the Devonian beds were superimposed. Next we find, in the same county, that elvans, or straight dykes of porphyritic felsite, have cut through the granite and the veins before mentioned, but have not penetrated the Devonian rocks. Subsequently to these elvans, veins of copper and lead were produced, being of a date certainly posterior to the Silurian, and anterior to the Devonian; for they do not enter the latter, and, what is still more decisive, streaks or layers of derivative copper have been found near Wexford in the Devonian, not far from points where mines of copper are worked in the Silurian strata.

Although the precise age of such copper lodes cannot be defined, we may safely affirm that they were either filled at the close of the Silurian or commencement of the Devonian period. Besides copper, lead, and silver, there is some gold in these ancient or primary metalliferous veins. A few fragments of tin found in Wicklow in the drift are also supposed to have been derived from veins of the same age.

Next, if we turn to Cornwall, we find there also the monuments of a very analogous sequence of events. First the granite was formed; then, about the same period, veins of fine-grained granite, often tortuous, penetrating both the outer crust of granite and the adjoining Palæozoic fossiliferous rocks, including the Coal-measures; thirdly, elvans holding their course straight through granite, granitic veins, and fossiliferous slates; fourthly, veins of tin also containing copper, the first of those eight systems of fissures of different ages already alluded to, p. 571. Here, then, the tin lodes are newer than the elvans. It has indeed been stated by some Cornish miners that the elvans are in some instances posterior to the oldest tin-bearing lodes; but the observations of De la Beche during the survey led him to an opposite conclusion, and he has shown how the cases referred to in corroboration can be otherwise interpreted. We may, therefore, assert that the most ancient Cornish lodes are younger than the Coal-measures of that part of England; and it follows that they are of a much later date than the Irish copper and lead of Wexford and some adjoining counties. How much later, it is not so easy to declare, although probably they are not newer than the beginning of the Permian period, as no tin lodes have been discovered in any red sandstone which overlies the coal in the south-west of England.

There are lead veins in Glamorganshire which enter the Lias, and others near Frome, in Somersetshire, which have been traced into the Inferior Oolite. In Bohemia, the rich veins of silver of Joachimsthal cut through basalt containing olivine, which overlies Tertiary lignite, in which are leaves of dicotyledonous trees. This silver ore, therefore, must have been formed in Tertiary times. In regard to the age of the gold of the Ural Mountains in Russia, which, like that of California, is obtained chiefly from auriferous alluvium, it occurs in veins of quartz in the schistose and granitic rocks of that chain, and is supposed by Murchison, De Verneuil, and Keyserling to be newer than the hornblendic granite of the Ural—perhaps of Tertiary date. They observe, that no gold has yet been found in the Permian conglomerates which lie at the base of the Ural Mountains, although large quantities of iron and copper detritus are mixed with the pebbles of those Permian strata. Hence it seems that the Uralian quartz veins, containing gold and platinum, were not formed, or certainly not exposed to aqueous denudation, during the Permian era.

In the auriferous alluvium of Russia, California, and Australia, the bones of extinct land-quadrupeds have been met with, those of the mammoth being common in the gravel at the foot of the Ural Mountains; while in Australia they consist of huge marsupials (p. 241). The gold of Northern Chili is associated in the mines of Los Hornos with copper pyrites, in veins traversing the Cretaceo-Jurassic formations, so called because its fossils are said to have the character partly of the Cretaceous and partly of the Jurassic fauna of Europe. The gold found in the United States, in the mountainous parts of Virginia, North and South Carolina, and Georgia, occurs in metamorphic Silurian strata, as well as in auriferous gravel derived from the same. In Queensland, according to the researches of Mr. Daintree, the auriferous lodes are entirely confined to those districts which are traversed by a series of pyritous diorites.

But Daintree discovered water-worn gold in a gravel containing

Glossopteris, a fern of late Carboniferous age, in Queensland, and Wilkinson found evidence that some gold occurred in quartz of pre-Carboniferous age in Victoria. It may be said that the gold of Australia is found in diorite dykes, cutting Upper Silurian and Devonian rocks. Auriferous pyrites impregnates the dykes, especially near their points of contact with the other rocks, and quartz-veins with gold intrude into the diorite. When the surface of the dyke has been exposed to terrestrial or subaërial denudation, the gold has been preserved in the gravels and clays; but when marine denudation has occurred, there is no gold to be found, or only in very small quantities. Basalts have overflowed the areas of denudation during the later Tertiary times, and have preserved the gravels. Although gold-bearing quartz-veins are found in New Zealand, of Cainozoic age, yet in Australia no gold-bearing dykes exist of Secondary or of Tertiary age. Their age is Palæozoic.

Gold has now been detected in almost every kind of rock, in slate, quartzite, sandstone, limestone, granite, and serpentine, both in veins and in the rocks themselves at short distances from the veins. In Australia it has been worked successfully not only in alluvium, but in veinstones in the native rock, generally consisting of Silurian shales and slates. In South Africa enormous deposits of gold have been found, not only in quartz-reefs, but in great beds of quartzose conglomerate (locally termed 'banket'), which are now very extensively mined. South Africa has now become one of the greatest gold-producing countries in the world.

Origin of gold in California and South America.—In 1864 Professor Whitney showed that the detrital gold deposits worked in California were of fluviatile origin and of two distinct ages. The more ancient or Pliocene gravel deposit had been protected by a cover of hard lava poured out over it from the volcanoes of the higher part of the Sierra; whilst the later, or Pleistocene auriferous gravels, formed since the period of greatest volcanic activity above alluded to, contained remains of the mastodon and elephant, and belong to the epoch of man. He also announced that some of the gold veins themselves were probably of Cretaceous age, as had been shown to be the case in South America by David Forbes. The last-mentioned mineralogist had already in 1861 advanced the opinion that the gold veins in South America and many other countries were of two distinct ages, and connected with the outbursts of granitic and also of dioritic rocks, the former or older being not later than the Carboniferous, and the latter as recent as the Cretaceous period.

John Arthur Phillips stated his belief in 1868 that the formation of recent metalliferous veins is now going on in various parts of the Pacific Coast. Thus, for example, there are fissures at the foot of the eastern declivity of the Sierra Nevada, in the State of that name, from which boiling water and steam escape, forming siliceous incrustations on the sides of the fissures. In one case, where the fissure is partially filled up with silica enclosing iron and copper pyrites, gold and cinnabar were found in the veinstone.

It has been remarked by De Beaumont that lead and some other metals are found in dykes of basalt as well as in mineral veins connected with volcanic rocks, whereas tin is met with in granite and in veins associated with plutonic rocks. David Forbes also found in

South America and elsewhere, that not only are metallic lodes intimately associated with the appearance of eruptive rocks in their vicinity, but also that their metallic contents are strongly influenced by the nature of the rock so intruded.

Although heated waters may have had much to do with the production of metalliferous veins, still it must be remembered that water of ordinary temperature, assisted by the presence of organic matter, will decompose and render soluble many minerals which may be re-precipitated by subsequent oxidation.

If different sets of fissures, originating simultaneously at varying levels in the earth's crust, and communicating some of them with volcanic, others with heated plutonic masses, be filled with different metallic ores, it will follow that those formed furthest from the surface will usually require the longest time before they can be exposed to our study. In order to bring them into positions within reach of the miner, upheaval and denudation must take place, and this will be greater in proportion as the fissures have lain deeper when first formed and filled. A considerable series of geological changes must intervene before any part of the fissures, which have been for ages in the proximity of the plutonic rocks so as to receive the gases discharged from them while cooling, can emerge into the atmosphere. But it is not necessary to enlarge on this subject, as the reader will remember what was said in the chapters on the chronology of the volcanic and hypogene formations.

In order that the reader may form an idea of the chemical composition of the metamorphic rocks described in the last four chapters, the following table of analyses is given.

ANALYSES OF CHIEF TYPES OF METAMORPHIC ROCKS

—	SILICA	ALUMINA	FERRIC OXIDE	FERROUS OXIDE	MAGNESIA	LIME	SODA	POTASH	WATER AND LOSS
MUSCOVITE-GNEISS (Saxony) .	75·2	15	1·9	—	—	·11	3·4	4·3	—
HORNBLENDE-GNEISS (Canada) .	69·2	14·8	2·6	—	1·0	2·1	4·3	4·3	0·7
SILLIMANITE - GARNET - GNEISS (Canada)	57·7	22·8	7·7	—	3·6	1·2	0·6	5·7	1·5
PYROXENE-GRANULITE (Saxony)	45·5	17·7	12·6	9·5	10·4	0·1	2·5	4·7	—
MICA-SCHIST (Saxony) . . .	66·2	18·6	—	5·3	1·2	0·4	2·2	3·9	2·0
PHYLLITE (Fichtelgebirge) . .	61·6	20·1	2·9	3·4	1·6	0·7	1·9	4·3	3·1
CLAY-SLATE (Wales) . . .	60·5	19·7	7·8	—	2·2	1·1	2·2	3·2	3·8
HORNBLENDE-SCHIST (Sweden) .	50·5	19·4	2·9	4·7	6·2	10·6	2·9	1·1	1·7
CHLORITE-SCHIST (Zermatt) .	42·1	3·5	—	26·8	17·1	1·0	—	—	11·2
TALC-SCHIST (Canada) . . .	51·5	3·6	—	7·4	22·4	11·2	—	—	3·6

PART VI

CONCLUSION

CHAPTER XLIII

GROUNDS FOR ACCEPTING UNIFORMITARIANISM AS THE BASIS OF GEOLOGICAL REASONING

Vastness of Geological Time—Proved by Physical and Palæontological evidence—Attempt to determine Time Ratios for the several geological periods—Attempts to measure geological periods in years—The doctrines of Catastrophism, Evolution, and Uniformitarianism—Evidences in favour of Uniformitarianism during the periods covered by the geological history—The Science of Geology limited to the study of the crust of the Globe—Bearing of speculations concerning the earth's interior on the Science of Geology—The Geological Record may only cover a small portion of the history of the Globe during past times.

Duration of Geological Time. Physical Evidence.—In studying the sedimentary and the volcanic rocks alike, we find abundant evidence that the periods of time required for their accumulation must have been exceedingly vast. Whether we consider the *maximum* or the *average* thicknesses of the strata deposited during the successive geological epochs, we are led to the conclusion that the masses of sediments, lavas and tuffs—often having an aggregate thickness of many miles—must have required for their formation periods of time that can only be measured in hundreds of thousands or even millions of years.

It has often been asserted, indeed, that to shorten the period required for the sequence of geological events, it is only necessary to suppose an increase in the energy of the agents of terrestrial change. But all the facts of the geological history, as we have endeavoured to illustrate in the foregoing pages, are entirely opposed to this idea of the 'hurrying up' of geological events and the consequent shortening of the geological record. Everywhere we find evidence that the strata forming the earth's crust were formed, not by violent debacles, but by slow and continuous operations, the vast effects of which could only

have been realised after periods of almost incalculable duration. The chalk strata consist of from one to two thousand feet of rock, built up entirely of minute and even microscopic organisms; and we know from the researches carried on during the *Challenger* expedition that the accumulation of such deep-sea oozes goes on with excessive slowness. Similar deposits of organic origin, as well as beds containing fossils, which exhibit many indications of long and quiet growth or of their having been eroded or encrusted by other organisms before being buried in sediment, abound among the representatives of all the geological systems, and testify to their slow formation. The old sands and muds, by their fine lamination, by the presence of surfaces covered with ripple-markings, sun-cracks, rain- and hail-prints, and the tracks and burrows of worms and other marine organisms, afford striking evidence of the deposition of their materials having taken place under conditions very similar to those of the present day. There are, of course, among the stratified rocks of the past, many masses of conglomerate and of materials indicating the action of rapid torrents, but there is not the smallest ground for inferring that such coarse materials are more abundant among the older formations of the earth's crust than among those which are being laid down at the present day; or that floods and tides acted upon a grander scale, or were more violent and oft-repeated in their operation, than in the existing oceans.

It must be remembered, too, that a large proportion of the materials thrown down in one place are redistributed and deposited in another; and this deposition and redeposition of material has in many cases gone on again and again, before the detritus has finally come to rest as part of a geological formation. In many cases—and this is especially true of the littoral and estuarine accumulations of great thickness—the piling up of the strata has been entirely dependent on the synchronous subsidence of the sea-bed, and this operation is one which, in the great majority of cases, we have reason to believe has taken place with extreme slowness.

Palæontological evidence of the duration of Geological Time.—There are two considerations that tend to reinforce our conclusions as to the slowness with which geological operations have taken place in the past. During the accumulation of many of the formations, it can be shown that great and remarkable changes in the distribution of sea and land have taken place. Thus the thin and comparatively insignificant formation known as 'the Upper Greensand'—as was pointed out by the late Mr. Godwin-Austen—was accumulated on a shore that was

slowly subsiding, the formation gradually encroaching over very considerable areas. In the case of more important formations, it may be proved that the sea has been shut out from certain areas, or has found access to new ones, and that the whole physical geography of the district has been changed, perhaps more than once, during the deposition of the system of strata; while we have no grounds for believing that such changes in physical geography—accompanied by modifications in the distribution of faunas and floras—took place with greater rapidity in past times than they do at the present day.

During the deposition of each of the great geological systems, the forms of life underwent slow but often constant and repeated modifications—old forms disappearing and new ones taking their place—and all the studies of botanists and zoologists point to the conclusion that such changes in organic life occur with extreme slowness. It has been argued, indeed, that if the conditions under which organic forms lived in the past varied more rapidly than at the present day, then casual variation and permanent modification may have been accomplished in shorter periods of time than at the present day, but, as we have seen, the geological record furnishes no evidence whatever of changes in physical conditions having taken place in the past more rapidly than in recent times.

If we turn our attention from sedimentary deposits to those of volcanic origin, it is impossible to assert that any accumulations of igneous materials associated with the older formations indicate more violent, more rapid, or more prolonged volcanic outbursts, or more abundant ejections of lavas and tuffs, than those of which we have evidence in Iceland, the Sandwich Islands, Etna, or the East Indian Archipelago at the present day.

All these considerations must be viewed in conjunction with the facts dwelt upon in Chapters XI. and XXIX., leading as they do to the conclusion that our geological record is only a series of fragments; the intervals separating successive periods being often of greater duration than the periods themselves—and we cannot fail to regard as inevitable the conclusion that the geological history, as sketched in the foregoing pages, must cover enormous periods of time.

Relative duration of the several Geological periods.—We have already seen that the late Professor Dana endeavoured to arrive at a conclusion concerning the ratios to one another of the periods required for the accumulation of the several systems of strata. His estimates are based on the *maximum* thicknesses of the strata belonging to different epochs in the North American continent, and in consideration of the extreme

slowness with which most organic deposits are laid down, the period allowed for the formation of a given thickness of limestone is five times as great as that for corresponding arenaceous or argillaceous beds. Dana's results have been employed in constructing the diagram on page 445; they are admittedly only a very rude approximation to the truth, but all geologists and palæontologists will probably agree that the periods represented by our several geological systems were not of anything like equal duration, and that the older systems represent vastly longer periods of time than the younger ones. Not only are the maximum and the average thicknesses of strata deposited during the Palæozoic periods far greater than those of the sediments formed in Mesozoic or Cainozoic periods, but the great changes which took place among creatures of lowly organisation also appear to indicate the lapse of enormous periods of time—the physical and the palæontological evidence being thus in complete accord.

Absolute duration of Geological periods.—The question of a possible determination of the length of geological periods in years has proved a fascinating problem to many inquirers. The most promising investigation having for its object the determination of a 'base-line' by which geological time may be measured in years is that derived from the study of the rate of recession of the falls of Niagara since glacial times.

In 1829, R. Bakewell arrived at the conclusion that the falls were receding at the rate of 3 feet per annum, and that about 10,000 years must have elapsed since the end of the glacial period. (Lyell, visiting the falls in 1841, and carefully reconsidering all the data, concluded that the time since the glacial epoch was probably 31,000 years.) G. K. Gilbert, W. Upham and other geologists of the U. S. Geological Survey, while pointing out many sources of error in all such calculations, incline to the adoption of periods ranging from 6,000 to 10,000 years; while J. W. Spencer arrives at a result almost identical with that of Lyell, namely, 32,000 years. It must, we think, be admitted that the sources of error in these calculations are so numerous, as to deprive the results of any value as an absolute measure of geological time; and this is equally true of calculations based on the growth of peat, stalagmite and other accumulations, or on the time required for denudation and sedimentation during past geological periods. Indeed the results actually arrived at by different observers, for the period of time which has elapsed since the commencement of the Cambrian to the present day, have varied from 70,000,000 years (Walcott) to 6,000,000,000 years (McGee).

Attempts to correlate Geological Periods with Astronomical Cycles.—We have seen in the preceding pages that many striking changes in climate have taken place, during past geological times, in different parts of the globe. Now it is evident that, if it were possible to refer any of these changes of climate to astronomical causes, we might be able to identify the particular planetary positions which corresponded to a certain set of climatal conditions. This being done, the astronomer, by calculating the date at which the required planetary arrangements existed, would not only fix the period at which the particular geological event took place, but would supply us with a base-line for the measurement of past geological times. The first attempt to apply astronomical calculations to the measurement of geological time was that made by the late Dr. James Croll. He fixed upon that remarkable episode in geological history known as the 'Glacial Period' as the most promising for his purpose, and he endeavoured to show that it may have resulted from the conjunction of certain well-known changes which take place periodically in the form of the earth's orbit, and in the inclination of the earth's axis. But the correctness of the reasoning of Dr. Croll concerning the effects of these changes has been questioned by many mathematicians and physicists; while Sir Robert Ball has suggested an alternative theory, which has, in turn, been adversely criticised by Mr. Culverwell and Professor George Darwin. There is, moreover, a very serious—indeed, it may be said a fatal—objection to all astronomical theories of climate. If true, we should have to admit the repeated occurrence of glacial epochs at regular intervals, and, although traces of glacial conditions have been found at a number of different periods of the earth's history, all physical and palæontological evidence is directly opposed to any such regularly alternating recurrence of periods of heat and cold during the epochs covered by the geological record.

Attempts to determine, from Physical data, the Period during which Life has existed upon the Earth.—From experiments made on the conductive power and other thermal constants of materials constituting the *crust* of the globe, Lord Kelvin, Professor Tait, and other authors have endeavoured to calculate the time which must have elapsed since the earth had so far cooled down as to permit of the existence of living beings upon its surface. Both the data and reasonings which have been relied upon in these calculations have been taken serious exception to by other mathematicians, such as Professors G. Darwin, O. Lodge, and J. Perry. All these calculations as to the rate of cooling of the globe proceed on the assumption that

the earth's interior is composed of materials which are comparable with, and indeed not greatly dissimilar to, those of the earth's crust. But, while we have *no certain knowledge whatever* of the composition of the central portions of our globe, all observation and reasoning point to the conclusion that not only are the materials in the interior of the earth under totally different physical conditions from those forming its crust, but chemically they may be very dissimilar. The deep-seated masses have certainly an average density *at least twice as great* as that of the rocks of the earth's crust; and the analogy of meteorites suggests that the highly oxidised condition of the materials of the crust is exceptional, and is not likely to extend to profound depths. The comparison of meteorites with some materials that have been brought up in volcanic eruptions from great depths, leads to the conclusion that iron, nickel, and other elements exist in an unoxidised condition in the earth's interior. It must be remembered, too, that reasonings concerning what is going on at great depths below the earth's crust, at high temperatures and enormous pressures, can only be based on experimental data, when the latter have been subjected to such extravagant extrapolation as to be deprived of all real value.

Setting aside, then, cosmological speculations, we will proceed to point out the principal views that have been maintained by different geologists, as the result of their study of the general facts of the earth's past history.

The doctrine of Catastrophism.—The older geological writers were in the habit of assuming that the present condition of the globe is the result of a series of short and violent actions. Mountain-chains, they thought, were suddenly thrust up from beneath the waters of the ocean, and by the violent floods thus produced thousands of feet of conglomerate, sandstone, and clay were accumulated in very short periods of time. Such theories take no account of the numerous facts pointing to slow and tranquil deposition among the rocks of the earth's crust, nor of the presence of the vast accumulations of calcareous and siliceous rocks made up entirely of the skeletons of minute and, indeed, often microscopic organisms—deposits that could only have been formed with extreme slowness. In the same way the great gaps in the series of stratified deposits were accounted for by the older geologists, as being due to terrible convulsions of nature which were supposed to have destroyed all living beings on the face of the globe, these being replaced by new creations of organisms. Such theories as these do not even attempt to account for the remarkable facts which we have pointed out of the relations of the fauna and flora of one geological period to

the fauna and flora of the period which preceded it; and further geological researches have shown that the supposed universal breaks in the system of geological formations have no real existence; for, as fresh areas are studied, new deposits are continually being discovered which serve to bridge over these gaps, and to make the record more and more continuous.

The doctrine of Evolution.—It has sometimes been asserted that in the earth's solid crust we find distinct evidence that the intensity of the agencies operating to produce change has undergone slow and progressive modifications, and that phases of development like those so familiar to the student of the organic world can be traced by the geologist in the physical history of the globe. But when the data upon which this conclusion is based come to be definitely formulated, it must be admitted that they are at the best slight and imperfect and quite insufficient for the establishment of generalisations of such a sweeping nature. There is no sufficient ground for the statement that the volcanic forces or the agents of denudation have operated either more or less powerfully at any former period of the earth's history than at the present day. While some geologists of repute have argued in favour of a gradual decline of volcanic activity during past geological times, others, like Professor Prestwich and Mr. Alfred Russel Wallace, have thought that the tendency has been towards an increase in the violence of igneous activities as time went on. There has been equal discrepancy of opinion with respect to the comparative potency of the agents of subaërial waste in past times and during the periods of human observation; and it must be admitted that there are no groups of facts which warrant the conclusion that great and progressive modifications either in one direction or the other have been taking place during geological times.

The doctrine of Uniformitarianism.—Geologists have now generally come to the conclusion that all the phenomena presented by the earth's solid crust can be accounted for by the slow and constant operation of forces identical in kind and not dissimilar in intensity to those which we can study still at work around us. That altogether new agencies have come into operation during the periods covered by the geological record, is a proposition which could only be maintained by those who assert that existing causes are totally inadequate for the production of the results witnessed. No one, probably, in the face of the mass of evidence which has been adduced, would now be prepared to defend such a conclusion. But it is still maintained by some that the energy of some of the agents at work on the globe has so far increased or declined as to lead to the production of

results which are not in any way commensurate with those following from the operation of the same agents at the present day. Some have argued that a gradual decline in the temperature of the earth's interior, due to secular cooling, or alterations in the heat emitted by the sun, or other cosmical changes, has produced very marked and recognisable variations in the nature and rate of the changes which have taken place in past geological times, as compared with those occurring at the present day.

The experience of mankind with respect to the operations of nature is limited to a few thousands of years, and anything like exact observations on those operations can scarcely be said to date back more than one hundred years. It would be the height of rashness to assert that in these short periods we have studied, or even witnessed, either the most violent or the most prolonged exhibition of the action of any of the terrestrial forces. We are, however, justified—in the absence of direct evidence to the contrary—in assuming that the forces acting in the past were 'of the same order of magnitude' as those now at work around us, and that effects, so similar to those being produced now, were due to causes similar in intensity as well as in nature to those which we witness in operation around us.

The late Professor Huxley in 1864, in an address to the Geological Society, endeavoured to formulate a theory of 'evolutionism' in opposition to that of 'uniformitarianism.' But in 1875, after careful reconsideration of the question, he wrote:—

'Applied within the limits of the time registered by the known fraction of the crust of the earth, I believe that Uniformitarianism is unassailable. The evidence that, in the enormous lapse of time between the deposition of the lowest Laurentian strata and the present day, the forces which have modified the crust of the earth were different in kind or greater in the intensity of their action, than those which are now occupied in the same work, has yet to be produced. Such evidence as we possess all tends in the contrary direction, and is in favour of the same slow and gradual changes occurring then as now.'

The limits of Geological inquiry.—Professor Huxley, however, was careful to qualify the passage which we have just quoted by the following remarks:—

'So far as the evidence afforded by the superficial crust of the earth goes, the modern geologist can, *ex animo*, repeat the saying of Hutton, "We find no vestige of a beginning, no prospect of an end." However, he will add with Hutton, "But

in thus tracing back the natural operations which have succeeded each other, and mark to us the course of time past, we come to a period in which we cannot see any further." '

We have pointed out at the commencement of this work that the conclusions of the geologist are entirely based on the study of the *crust* of the globe, or that thin superficial portion which is accessible to his observations. How small is that crust, as compared with the whole mass of the globe, will be shown by a reference to the following diagram.

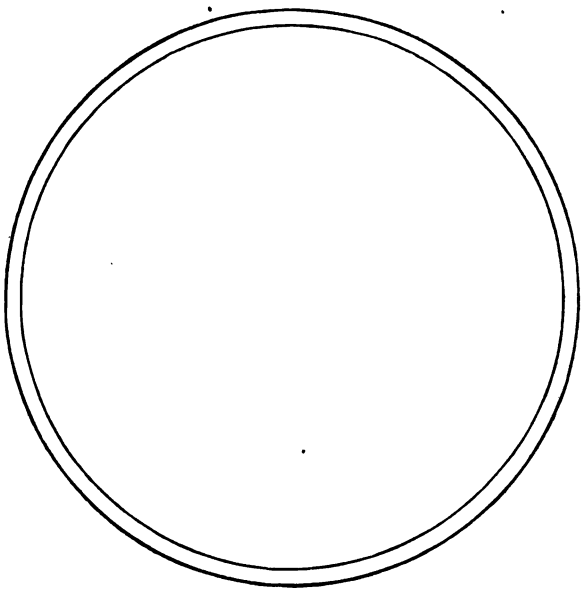
Concerning the nature of the earth's interior, all that we know with certainty is that it has a specific gravity twice as great as that of the materials forming the crust; but whether this high density is to be ascribed to a different chemical composition, or to the molecules of the mass being squeezed together by the enormous pressure to which it is subjected, we can only speculate. Of the properties and the behaviour of matter, whether of known or unknown composition, under conditions which we can never hope to imitate, it behoves us to speak with some diffidence and reserve.

The astronomer may find good reasons for ascribing the earth's form to the original fluidity of the mass in times long antecedent to the first introduction of living beings into the planet; but the geologist must be content to regard the earliest monuments which it is his task to interpret as belonging to a period when the outer shell of the earth had already acquired great solidity and thickness, probably as great as it now possesses, and when volcanic rocks not essentially differing from those now produced were formed from time to time, the intensity of volcanic heat being neither greater nor less than it is now. This heat has, no doubt, given rise at successive periods to many of the leading changes in the form and structure of the earth's crust; but their magnitude is by no means such as to warrant our invoking the igneous fusion of the whole planet to account for them. If the reader will refer to the diagram (fig. 736), he may convince himself that a machinery more utterly disproportionate to the effects which it is required to explain was never appealed to. The outer circular line of the diagram represents a portion of the earth's diameter equal to 25 miles; so that if the loftiest mountain-chains, even such as the Himalaya, 5 miles in their greatest height, could be marked by white marks within this line, they would form a feature in it which would be scarcely appreciable

The space between the two circles, including the thickness of the lines themselves, has a breadth or diameter of 200 miles. Let us then suppose very thin lines 2 inches long, and equal in

width to only ⅛ of the outer line, to be drawn here and there within this shell of 200 miles in thickness. These lines, faint and unimportant as they would appear, might nevertheless represent sections of seas and oceans of melted lava 5 miles deep and 5,000 miles across. It cannot be denied that the expansion, melting, solidification, and shrinking of such subterranean seas of lava at various depths, might suffice to cause great movements and earthquakes at the surface, and even lead to the production of

Fig. 736.



Section of the earth, in which the breadth of the outer boundary line represents a thickness of 25 miles; the space between the circles, including the breadth of the lines, 200 miles.

rents in the earth's crust several thousand miles long, such as may be implied by the lineally arranged cones of the Andes or mountain-chains like the Alps.

Considerations such as these may well lead us to pause before attempting to frame a system of cosmogony, based on the slender data which we possess concerning the nature of the earth's interior; and if we choose to indulge in speculations upon the subject at all, it must always be borne in mind that

the conclusions of geology, derived from a study of the earth's crust, rest on other and far more trustworthy evidence.

For the geologist to abandon the basis of solid facts derived from the study of the earth's crust and to indulge in vague speculations concerning the altogether unknown interior of the earth, would be as unwise as for the historian to neglect all written and other records of the past, in order to base his science on a series of guesses concerning the origin and destiny of the human race.

Supposed limitation of the Period covered by the Geological History.—Astronomers and physicists have sometimes been led to speculate on the possible limitation of the geological periods—(1) from known facts concerning the rate of secular cooling in the globe; (2) from the effects of tidal retardation in changing the figure of the earth; (3) from the gradual diminution of the sun's heat by dissipation of energy; and limits of time varying between 10,000,000 and 400,000,000 years have been suggested for the duration of the earth as a home for living beings. It may very well be that some of the periods named by physicists are quite adequate for the requirements of the geologist; but, in any case, while so much difference of opinion exists between different physicists concerning the *data* on which these calculations are based—and in our absolute ignorance of the real nature of the earth's interior, and of the source of the sun's energy, it is hard to see how these differences can ever be removed—it is unwise to attach importance to any conclusions of the kind.

Geological history and the supposed Primæval state of the Globe.—We have seen that a strong desire has been manifested to discover in the ancient rocks the signs of an epoch when the planet was uninhabited, and when its surface was in a chaotic condition and uninhabitable. The opposite opinion, indeed, that the oldest of the rocks now visible may be the last monuments of an antecedent era in which living beings may already have peopled the land and water, has been declared to be equivalent to the assumption that there never was a beginning to the present order of things.

With equal justice might an astronomer be accused of asserting that the works of creation extended through infinite space, because he refuses to take for granted that the remotest stars now seen in the heavens are on the utmost verge of the material universe. Every improvement of the telescope has brought thousands of new worlds into view; and it would therefore be rash and unphilosophical to imagine that we already survey the whole extent of the vast scheme, or that it will ever be brought within the sphere of human observation.

But no argument can be drawn from such premises in favour of the infinity of the space that has been filled with worlds; and if the material universe has any limits, it then follows that it must occupy a minute and infinitesimal point in infinite space.

So if, in tracing back the earth's history, we arrive at the monuments of events which may have happened millions of ages before our times, and if we still find no decided evidence of a commencement, yet the arguments from analogy in support of a beginning remain unshaken; and if the past duration of the earth be finite, then the aggregate of geological epochs, however numerous, must constitute a mere moment of the past, a mere infinitesimal portion of eternity.

It has been argued that as the different states of the earth's surface, and the different species of animals and plants by which it is inhabited, have all had their origin, and many of them their termination, so the entire series may have commenced at a certain period. We are far from denying the weight of this reasoning from analogy; but although it may strengthen our conviction that the present system of change has not gone on from eternity, it cannot warrant us in presuming that we shall be permitted to behold the signs of the earth's origin, or the evidences of the first introduction into it of organic beings. We aspire in vain to assign limits to the works of creation in *space*, whether we examine the starry heavens, or that world of minute objects which is revealed to us by the microscope. We are prepared, therefore, to find that in *time* also the confines of the universe lie beyond the reach of mortal ken.

As geologists, we learn that it is not only the present condition of the globe which is suited to the accommodation of myriads of living creatures, but that many former states also were adapted to the organisation and habits of prior races of beings. The disposition of the seas, continents and islands, and the climates have varied; the species of animals and plants have been changed; and yet they have all been so modelled, on types analogous to those of existing plants and animals, as to indicate throughout a perfect harmony of design and unity of purpose. To assume that the evidence of the beginning and end of so vast a scheme lies within the reach of our philosophical enquiries, or even of our speculations, appears to be inconsistent with a just estimate of the relations which subsist between the finite powers of man and the attributes of an Infinite and Eternal Being.

APPENDIX A.

THE COMMON ROCK-FORMING MINERALS.

MINERALOGISTS variously estimate the number of distinct mineral species at from 500 to 800. Of these only 30 or 40 occur at all commonly as rock-constituents, while less than a dozen of them make up the great mass of the Earth's crust.

Rock-forming minerals may be original (*authigenic*), that is produced at the time of the first formation of the rock, or secondary (*epigenetic*), that is, they may result from processes of change that have affected the original minerals of the rock. The minerals which make up the great mass of a rock are called *essential* minerals; additional minerals which may be present in the rock—usually in smaller quantities—are spoken of as *accessory* minerals.

On fractured surfaces of rocks, and still better in thin transparent sections, it will be seen that some minerals have their crystals fully developed so as to exhibit the outward forms proper to them; such minerals are said to be *idiomorphic* or *automorphic*. When their outer form is not exhibited, owing to their development having been interrupted by the contiguity of other crystals, they are said to be *allotriomorphic* or *xenomorphic*.

For full descriptions of the rock-forming minerals the student is referred to the treatises on mineralogy by Rutley, Bauerman, and other authors, to Prof. E. S. Dana's 'Minerals and how to study them,' and for fuller details to Dana's 'System of Mineralogy.' The optical characters of the rock-forming minerals as seen in thin sections are described in Idding's translation of Rosenbusch's 'Microscopical Physiography of the Rock-forming Minerals.'

The rock-forming minerals fall into a few well-marked groups, and their distinctive characters are indicated in the following lists, the following abbreviations being employed—G, specific gravity; H, hardness. The Roman numerals indicate the six systems of crystallisation (I. Cubic, II. Tetragonal, III. Hexagonal, IV. Rhombic, V. Monoclinic, VI. Triclinic). Cl. Cleavage, Pleoc. Pleochroism, Refr. Refractive Index, Pol. Polarisation, Comp. Chemical Composition.

A. MINERALS CONSISTING OF SILICA.

Quartz. III. (rhombohedral and tetartohedral) without twinning, but showing parallel growths. Cl. none. H=7, G=2·65. Usually colourless and clear without traces of alteration. Generally contains many cavities (gas, liquid, glass, and stone), with inclusions of other minerals. Refr. same as Canada Balsam. Pol. moderately bright tints. Comp. SiO_2

[Quartz is sometimes coloured purple (amethyst), yellow (citrine and cairngorm), green (chrysoprase), pink (rose-quartz), black (smoky quartz and morion). Varieties with inclusions are known as false cat's eye, tiger's eye, avanturine quartz, plasma, &c.]

Opal. Uncrystallised (amorphous or colloid). H = 5·5 – 6·5, G = 2·2. Colourless (hyalite or Muller's glass), coloured by various impurities (common opal), or showing both opalescence and play of colours (precious opal, fire opal, &c.). Isotropic except when under strain. Refr. less than quartz. Comp. SiO_2, usually contains some water, very variable in amount, which must be regarded as accidental.

Chalcedony is the name given to mixtures of colloid and crystalline silica. Nearly opaque forms are known as Jasper, varieties more or less translucent as Agates. Flint and chert are varieties of chalcedonic silica.

[Other crystalline varieties of silica are known as Tridymite (hexagonal and twinned), Christobalite (cubic), &c. Forms of chalcedonic silica have received the names of Quartzine, Lutecite, &c.]

B. Alumino-alkaline Silicates.

The Felspar Group.

The felspars crystallise in the monoclinic and triclinic system, they are usually twinned, and have two well-marked cleavages at angles near 90°. H = 6, G = 2·54 – 2·75. Refr. less than Canada Balsam. Pol. lower (neutral) tints than quartz. They consist of silicate of alumina with silicate of potash, soda, and lime, and exhibit many varieties dependent on the proportions of these constituents. The felspars are isomorphous mixtures of these silicates, and are the most abundant of all the rock-forming minerals. The chief varieties are as follows. The monoclinic forms, in which the cleavages are at right angles and which are called *orthoclastic* felspars; the triclinic forms, in which the cleavage angle differs from a right angle and which are said to be *plagioclastic* felspars; the latter exhibit lamellar twinning in polarised light.

Orthoclase (Potash-felspar). The clear varieties are known as Sanidine. Orthoclase is monoclinic and simply twinned. Cleavages at right angles. Common in acid igneous rocks.

Microcline. Similar in composition and general characters to orthoclase, but with a slightly oblique cleavage, and a peculiar internal structure (cross-hatched) which is seen in thin sections under polarised light.

Albite (Soda-felspar). Plagioclastic and showing lamellar twinning in polarised light. Usually occurs as a secondary mineral in rocks.

Oligoclase (Soda-lime felspar). Plagioclastic with lamellar twinning. Common in acid and intermediate rocks.

Andesine (Soda-lime felspar). Plagioclastic with lamellar twinning. Common in intermediate rocks.

Labradorite (Lime-soda felspar). Plagioclastic with lamellar twinning. Common in basic rocks.

Anorthite (Lime-felspar). Plagioclastic with lamellar twinning. Found principally in ultrabasic rocks.

The Felspathoid Group.

The felspathoids play much the same part in rocks as the felspars. While the latter are found everywhere, however, the former have a very local distribution. The felspathoids are silicates of alumina,

with silicates of the alkalies and lime, but they sometimes contain compounds with chlorine, sulphur, &c. They crystallise in the cubic, tetragonal, and hexagonal systems. Like the felspars they are sometimes original and sometimes secondary minerals. They are usually much less stable than the felspars.

Leucite. I. Cl. none. G = 2·45–2·56, H = 5·5–6. Refr. less than Canada Balsam. Pol. isotropic or with faint traces of lamellar twinning. Found in basaltic rocks &c. in Italy, Bohemia, &c. Comp. Silicate of alumina and potash.

Nosean and **Hauyn.** I. G = 2·27–2·5, H = 5·5–6. Often contain many inclusions. Isotropic. Found in phonolites and basaltic rocks. Comp. Silicate of alumina, soda, and lime with sulphur compounds.

Sodalite is a somewhat similar cubic mineral (silicate of alumina and soda with chlorine and sulphur compounds), found in trachytes, &c.

Scapolite. II. G = 2·6–2·8, H = 5–6. Comp. Silicate of alumina, lime, and soda with chlorine compounds. Found in altered gneisses, &c.

Melilite is a somewhat similar tetragonal mineral found in basaltic and ultrabasic rocks.

Nepheline (Elæolite). I. G = 2·55–2·61, H = 5·5–6. Refr. low. Pol. low tints. Inclusions common and symmetrically arranged. Found in phonolites and some basaltic rocks.

C. The Ferro-Magnesian Silicates.

These contain silicates of iron, magnesia, and lime, the silicates of alumina and soda being also sometimes present. They fall into three groups—the Micas, the Amphibole-Pyroxene group, and the Olivines. The micas, through Muscovite, are closely related chemically to the Alumino-alkaline silicates.

THE MICA GROUP.

The micas are minerals crystallising in the monoclinic system (but pseudo-hexagonal in habit) with a strong basal cleavage; the true micas are distinguished from other minerals of the same habit (micaceous minerals) by the elasticity of the plates into which their crystals so readily split up. While Muscovite is really an alumino-alkaline silicate and may be formed from orthoclase by alteration, the Phlogopites and Biotites are ferro-magnesian silicates, playing the same part in rocks as the pyroxenes, amphiboles, and olivines.

Muscovite. V. G = 2·76–3, H = 2–2·5. Pol. very high. Biaxial. Colourless. Comp. Potash-mica. Found in granites and other acid rocks, gneisses, schists, &c.

Biotite. V. G = 2·7–3·1, H = 2·5–3. Pol. very high. Pleoc. very strong with great absorption. Usually highly coloured. Comp. Magnesia- and iron-micas. Found in intermediate and basic rocks, and frequently as a secondary mineral.

A form of mica with much lithium is known as **Lepidolite.** Others contain chromium (**Fuchsite**), manganese (*Manganophyllite*, &c.).

Lepidomelane is a black mica common in granites.

Phlogopite a dark-coloured mica usually found in metamorphic limestones.

The 'Hydromicas' are the result of the alteration of micas both of the Muscovite series (Damourite, Sericite, Gilbertite, &c.) and of the Biotite series (Hydrobiotite &c.).

THE PYROXENE-AMPHIBOLE GROUP.

The Pyroxene-Amphibole group illustrate in striking manner what mineralogists call iso-dimorphism. Crystallising in the monoclinic and rhombic systems (and occasionally in the triclinic system), and consisting of isomorphous mixtures of silicates of magnesia, iron, and lime (occasionally with alumina and soda silicates), they present two distinct habits of crystallisation. The pyroxenes have a prismatic cleavage with an angle of near 90°; the amphiboles have a prismatic cleavage of about 125°. Pyroxenes and amphiboles differ too in their specific gravity, optical properties, stability, &c. Amphiboles can be converted into pyroxenes by fusion and slow cooling. The pyroxenes tend, however, to pass back slowly into amphiboles (*paramorphic* change). A mineral of the pyroxene group may be found partially converted into an amphibole, as in Uralite.

The chief pyroxenes are:—

Augite. V. G = 3·2–3·5, H = 6·5. Deep-coloured. Pleoc. slight Pol. high. Very common in basic rocks.

Sahlite and **Malacolite** are pale-coloured augites. **Diopside**, **Fussaite**, and **Omphacite** are green augites. **Ægerine** is a soda-augite.

Diallage is an altered augite (brown or green) with a basal parting and sub-metallic lustre. Found generally in basic plutonic rocks (gabbros).

Enstatite. IV. Pol. low. Pleoc. marked in coloured varieties. The ferriferous varieties of Enstatite are called **Bronzite**, the highly ferriferous varieties are known as **Hypersthene.**

The chief amphiboles are:—

Hornblende. V. G = 2·9–3·4, H = 5–6. Pol. strong. Pleoc. high. Very common in metamorphic and some igneous rocks.

Tremolite is a colourless hornblende, **Actinolite** is a green hornblende, and **Arfvedsonite**, **Glaucophane**, **Riebeckite**, &c., are soda-hornblendes, which sometimes assume blue tints.

Anthophyllite (IV.) is an amphibole corresponding to Enstatite in the Pyroxene series.

THE OLIVINE GROUP.

This group consists of basic silicates of magnesia and iron (occasionally with lime). The minerals of the group occur in basic and especially in ultrabasic rocks (Peridotites).

Olivine (or Peridot). IV. G = 3·4, H = 6–7. Green to black in colour. Colourless in thin sections. Pol. high tint. Very easily undergoing alteration and easily changed to serpentine.

D. THE OXIDES OF IRON, TITANIUM, &c.

These are very widely diffused, but form a large part of rocks only of the basic and ultrabasic groups.

Magnetite. I. G = 4·9–5·2, H = 5·5–6·5. Opaque, black, and

submetallic. Often showing alteration to red, brown, and yellow (hydrated) products. Comp. FeO, Fe_2O_3.

Titanoferrite. III. G = 4·5–5, H = 5–6. Opaque, black, and submetallic, but showing white decomposition products. Comp. $FeO_1Ti_2O_3$.

Rutile. II. G = 4·18–4·25, H = 6–6·5. Reddish brown to yellow—translucent. Usually in very small crystals (twinned), often enclosed in other minerals. Comp. TiO_2.

Anatase and **Brookite,** two other forms of TiO_2, are probably formed by alteration of Rutile.

Hematite (III.) (hexagonal plates, blood-red by transmitted light) is formed by oxidation of magnetite. Comp. Fe_2O_3. Various brown and yellow oxides result from the hydration of hematite.

Corundum (Al_2O_3); the Spinels (**Picotite, Chromite,** &c.) and **Cassiterite** (SnO_2) occur more rarely in rocks.

E. Accessory Minerals.

Apatite. III. G = 2·92, H = 4·5–5. Comp. Phosphate of calcium with chloride or fluoride of calcium. Very common in small quantities in igneous and metamorphic rocks.

A phosphate of yttrium and the cerium metals called **Monazite** is present in very minute crystals in many rocks.

Zircon. II. G = 4·6–4·7, H = 7·5. Comp. SiO_2,ZrO_2. Like the above very frequent in small crystals enclosed in all the constituents of rocks.

Sphene. V. Often in wedge-shaped crystals, brown or colourless. G = 3·4–3·6. Comp. Calcium silico-titanite. A primary constituent of some rocks, and the result of alteration of titanoferrite in others.

F. Minerals especially found in Rocks produced by Contact Metamorphism.

Garnet. I. G = 3·15–4·3, H = 6·5–7·5, fusible. Comp. Isomorphous mixtures of compounds of aluminium, iron, chromium, and titanium sesquioxides with the protoxides of iron, magnesium, lime, &c. Found both in igneous and metamorphic rocks.

Topaz. IV. G = 3·4–3·65, H = 8. Comp. Aluminium silicate with fluorine. Colourless, higher refractive index than quartz.

Tourmaline. III. Hemimorphic. G = 2·98–3·2, H = 7–7·5. Colour very various. Pleoc. strong. Comp. Borosilicate of aluminium, calcium, iron, &c.

Andalusite (*Chiastolite*) (IV., **Sillimanite** (*Fibrolite*) (IV.), and **Kyanite** (VI.) are forms of aluminium silicate.

Cordierite (IV.) and **Staurolite** (IV.) are more complicated compounds of aluminium with magnesium and iron silicates.

Epidote (V.) and **Zoisite** (IV.) are aluminium and calcium silicates, sometimes with iron, manganese, &c. (**Piedmontite**).

G. Secondary Minerals.

Almost any of the minerals already named may occur as secondary constituents of rocks, but certain minerals like the following seldom occur as primary constituents of igneous rocks.

(*a*) *Micaceous Minerals* (pseudo-hexagonal with strong basic cleavage).

Chlorites. V. Hydrous aluminium silicates with silicates of magnesium and iron. Usually exhibiting green tints.

Chloritoids (*Brittle Micas*). V. Very varied in composition, *e.g.* **Ottrelite, Masonite**, &c.

Vermiculites. Other hydrated minerals which exfoliate and curl up under the blowpipe.

Kaolin. V. G = 2·6, H = 2–2·5. Hydrous aluminium silicates. This and other similar compounds form the basis of most clays.

Talc (Steatite). V. G = 2·7–2·8. H = 1. Comp. Hydrous magnesium silicate.

(*b*) *Non-micaceous Minerals.*

Zeolites. Hydrated alumino-alkaline minerals. They boil up in the blowpipe flame, hence their name.

Calcite. III. G = 2·72, H = 3. Cleavage and twinned character strongly marked. Comp. $CaCo_3$.

Aragonite IV. G = 2·95, H = 3·5–4. Another form of calcium carbonate.

Dolomite. III. G = 2·8–2·9, H = 3·5–4. Comp. $(CaMg)CO_3$.

Gypsum. IV. G = 2·3, H = 2. Comp. $CaSO_4 + 2H_2O$.

The hydrous oxides have already been noticed; they occur frequently as secondary constituents of rocks.

H. Minerals of the Heavy Metals ('Ores').

These are found in veins or other ore deposits, or, more rarely, diffused in small quantities through igneous, aqueous, and metamorphic rock-masses. They are usually inter-crystallised with various sparry minerals (veinstones), such as **Quartz, Calcite, Fluorspar** (calcium fluoride), **Barytes** (barium sulphate, &c.).

The ores found in the upper part of veins ('gossans') are either oxides like **Magnetite, Hematite, Cuprite** (copper oxide), **Zincite** (zinc oxide), &c., or hydrated oxides, like those of iron (**Göthite, Limonite, Xanthosiderite**), of manganese (**Manganite, Psilomelane**), &c. With these occur Carbonates, like those of iron (**Chalybite**), of zinc (**Calamine**), of copper (**Malachite, Azurite**), of lead (**Cerussite**), &c., with various sulphates, silicates, phosphates, and other salts.

The deeper portions of ore-deposits are usually characterised by the presence of sulphides, among the commonest of which are those of iron (**Pyrite, Marcasite, Pyrrhotite**), of lead (**Galena**), and of zinc (**Blende**). With these occur many complex compounds of sulphides, selenides, tellurides, arsenides, and antimonides.

Some of the less oxidisable metals (gold, platinum, &c.) usually occur 'native' (uncombined), or as alloys or amalgams; and silver, copper, and mercury are also not unfrequently found in the unoxidised condition.

Iron, alloyed with nickel or platinum, similar to the iron meteorites (siderites), has been found in igneous masses at Ovifak in Greenland, Santa Catharina (?) and Ribiera in Brazil, Awarua in New Zealand, Josephine in Oregon, and Ekaterinberg in the Urals,

APPENDIX B.

CLASSIFICATION OF PLANTS, LIVING AND FOSSIL.

Names printed in italic capitals are those of groups which are not found preserved as fossils. Those printed in capitals have both fossil and living representatives. Those in thick type are extinct.

A. CELLULAR CRYPTOGAMS (spore-bearing plants with cellular tissue only).

MYXOMYCETES. (Slime-fungi living on dead organisms or causing plant-diseases).

DIATOMACEÆ. (Unicellular with siliceous skeletons).—Tertiary.—

SCHIZOPHYTA. (Oscillatoria, micrococcus, bacteria, &c.)

ALGÆ. Freshwater and marine (including calcareous forms like Lithothamnion, Siphonieæ, Chara, &c.). Camb.—

FUNGI. (Peronosporites, Discomycetes, &c.). Sil.—

BRYOPHYTA { HEPATICEÆ. (Jungermannia, Marchantia, &c.) Tertiary— MUSCI. (Sphagnum, Hypnum, &c.) Tertiary—

B. VASCULAR CRYPTOGAMS. (Spore-bearing plants with vascular tissue.)

EQUISETACEÆ. (Horsetails.) Trias.—

Calamarieæ. (Calamites.) Dev.—Perm.

Sphenophylleæ. (Sphenophyllum, &c.)—Carb.

LYCOPODINEÆ. (Club-mosses.) Tertiary.—

SELAGINELLEÆ. (Selaginellas.) Tertiary.—

Lepidodendreæ. Lepidodendron, &c. Dev.—Perm.

Stigmarieæ (?). Stigmaria &c. Dev.—Perm.

Sigillarieæ. Sigillaria, &c. Sil. (?)—Perm.

FILICINEÆ. Ferns. Dev. —

(According to Williamson and Scott, certain carboniferous plants form a link between the ferns and the cycads.)

C. PHANEROGAMS (seed-bearers). GYMNOSPERMS (naked-seeded).

CYCADEÆ. (Cycas, Zamia, &c.) Dev.—

GNETACEÆ. (Gnetum, &c.)

Cordaiteæ. (Cordaites, &c.) Carb.

CONIFERÆ. (Pines, Firs, Yews, &c.) Dev.—

D. PHANEROGAMS. ANGIOSPERMS (with seeds in seed-vessels).

MONOCOTYLEDONES. Endogenous plants. Palms, grasses, &c. Trias—

DICOTYLEDONES. Exogenous plants. Higher forms of vegetable life. Cret.—

APPENDIX C.

CLASSIFICATION OF ANIMALS, LIVING AND FOSSIL.

The names in italic capitals are forms without hard parts that have left no relics in fossil forms. Those printed in capitals have fossil and living representatives. Those printed in thick type are extinct. The groups are orders or suborders.

SERIES I.—PROTOZOA (Lowest forms of life).

MONERA. (*Protamœba, &c.*)
PROTOPLASTA. (*Amœba, &c.*)
GREGARINIDA. (*Gregarina, &c.*)
CATALLACTA (*Megasphæra, &c.*)
INFUSORIA (*Paramœcium, &c.*)
FORAMINIFERA (Rhizopoda Reticulata). Calcareous shells. Chambers communicating by small holes (foramen). Pre-Cambrian (?).—
RADIOLARIA (Rhizopoda Radiolaria). Siliceous skeletons (occasionally horny or partially horny). Pre-Cambrian (?).—

SERIES II.—PORIFERA (Spongida).

MYXOSPONGIA. (*Halisarca, &c.*)
CERATOSPONGIA. (Horny sponges *Ceratina, &c.*)
Silico-spongida:
MONACTINELLIDA. (*Cliona, &c.*) Carb.—
TETRACTINELLIDA. (*Geodia, &c.*) Carb.—
LITHISTIDA. (*Siphonia, &c.*) Camb.—
HEXACTINELLIDA. (*Ventriculites, &c.*) Camb.—
CALCISPONGIDA. (Calcareous sponges.) Jura.—
Pharetrones. (Extinct forms of calcareous sponges). Dev.—Cret.

SERIES III.—CŒLENTERATA (Zoophyta).

Hydrozoa.
SIPHONOPHORA. (*Physalia, &c.*)
DISCOPHORA. (Acalepha, Medusæ or jelly-fish). Camb. (?).—
TUBULARIA. (*Hydractinia, Parkeria ? &c.*) Trias (?).—
CAMPANULARIA. (*Campanula, Dictyonema, &c.*) Camb. (?).—
Graptolithida (Rhabdophora. Graptolites). Camb. (?)—Sil.
HYDROCORALLARIA. (*Stylaster, Millepora, &c.*) Tertiary.—
Stromatoporidea. (Stromatoporoids.) Ord.—Perm.

Actinozoa.
- OCTOCORALLA. (Alcyonaria.) Sil.—
- HEXACORALLA. (Zoantharia.) Trias.—
- **Tabulata.** (*Monticuliporida*, &c.) Sil.—Cret.
- **Tetracoralla.** (Rugosa.) Ordov.—Perm. (?).
- *CTENOPHORA.* (*Beroë.*)

SERIES IV.—ECHINODERMATA.

Cystoidea. (*Cystids*, with *Agelacrinus.*) Camb.—Perm. (?)
Blastoidea. (*Pentremites*, &c.) Sil.—Carb.
CRINOIDEA. (Other stalked forms.) Camb.—
ASTEROIDEA. (Common star-fish.) Sil.—
OPHIUROIDEA. (Brittle star-fish.) Sil.—
Palechinoidea. (*Palæchinus*, *Melonites*, &c.) Ordov.—Cret.
EUECHINOIDEA. (Sea-urchins.) Trias.—
HOLOTHURIDEA. (Sea-slugs.) Tertiary.—

SERIES V.—ANNULOIDEA (Annelida, Vermes, Worms).

TURBELLARIA. (*Planaria*, &c.)
ROTIFERA. (*Hydatina*, &c.)
TREMATODA. (*Aspidogaster*, &c.)
CESTOIDEA. (*Tænia*, Tapeworm, &c.)
MYZOSTOMATA. (*Myzostomum.*)
GEPHYREA. (*Sipunculus.*)
HIRUDINEA. (*Hirudo*, Leech.)
OLIGOCHÆTA. (*Lumbricus*, Earth-worms.)
POLYCHÆTA. (*Aphrodita*, *Serpula*, &c.) Camb. (?).—

SERIES VI.—MOLLUSCOIDEA.

Bryozoa or Polyzoa.
- *PODOSTOMATA.* (*Rhabdopleura*, &c.)
- *PHYLACTOLÆMATA.* (*Plumatella*, &c.)
- CYCLOSTOMATA. (*Idmonea*, &c.) Ordov.—
- *CTENOSTOMATA.* (*Alcyonidium*, &c.)
- CHEILOSTOMATA. (*Eschara.*) Jura.—
- *PEDICILLINEA.* *Pedicellina.*

BRACHIOPODA INARTICULATA. (*Lingula.*) Camb.—
BRACHIOPODA ARTICULATA. (*Terebratula.*) Camb.—

SERIES VII.—MOLLUSCA.

LAMELLIBRANCHIATA. (Pelecypoda, Conchifera, Bivalvia. Camb.—
SCAPHOPODA. (*Dentalium.*) Sil.—
POLYPLACOPHORA. (*Chiton*, &c.) Sil.—
HETEROPODA. (*Atlanta*, *Bellerophon*, &c. ?) Camb. (?)—
GASTROPODA. (Whelks, &c.) Camb.—
PULMONATA. (Snails.) Dev.—

Cephalopoda.

NAUTILOIDEA. (*Nautilus, Orthoceras.*) Camb.—
Ammonoidea. (Ammonites, Goniatites.) Dev.—Cret.
BELEMNOIDEA. (Belemnites, *Spirula.*) Trias.—
SEPIOIDEA. (*Sepia Geoteuthis.*) Jura.—
OCTOPODA. (*Octopus.*) Cret.—

SERIES VIII.—ARTHROPODA.

NEMATOIDEA. (Thread-worms, &c.)
NEMATORHYNCHA. (*Chætonotus*, &c.)
ACANTHOCEPHALA. (*Echinorhynchus.*)
CHÆTOGNATHA. (*Sagitta.*)
PROTOTRACHEATA. (*Peripatus.*)

Myriapoda.

Protosyngnatha. (*Palæocampa.*) Carb.
CHILOPODA. (Centipedes.) Tertiary—
Archipolipoda. (*Xylobius.*) Dev.—Perm.
DIPLOPODA. (Millepedes.) Cret.—

Arachnida.

PENTASTOMIDA. (*Pentastoma.*)
ARCTISCA. (*Macrobiotus.*)
PYCNOGONIDA. (*Nymphon.*)
ACARINA. (Mites.) Tertiary—
ARANEINA. (Spiders.) Carb.—
ARTHROGASTRA. (Scorpions.) Sil.—

Insecta.

THYSANURA. (*Podura.*)
ORTHOPTERA. (May flies, &c.) Sil. (?)—
Palæodictyoptera. (*Palæoblattina*, &c.) Ordov. (?)—Carb.
RHYNCHOTA. (Bugs, &c.) Tertiary—
DIPTERA. (House flies, &c.) Jura.—
LEPIDOPTERA. (Butterflies and moths.) Jura.—
NEUROPTERA. (Caddis flies, &c.) Carb.—
HYMENOPTERA. (Bees, wasps, and ants.) Jura.—
COLEOPTERA. (Beetles.) Jura.—

Crustacea.

Eurypterida. (*Eurypterus, Pterygotus.*) Sil.—Carb.
XIPHOSURA. (King crabs.) Sil.—
Trilobita. (Trilobites.) Camb.—Perm.
PHYLLOPODA. (*Apus*, &c.) Camb.—
CLADOCERA. (Water-fleas.)
OSTRACODA. (*Cypris*, &c.) Camb.—
COPEPODA. (*Cyclops.*)
RHIZOCEPHALA. (*Peltogaster.*)
CIRRIPEDIA. (Barnacles.) Sil.—
AMPHIPODA. (Sand hoppers.) Sil.—
ISOPODA. (Wood lice, &c.) Jura.—
STOMATOPODA. (*Squilla.*) Carb. (?)—
ANOMOURA. (Hermit crabs.) Cret.—
BRACHYURA. (Crabs.) Dev.—
MACROURA. (Lobsters, &c.) Carb.—

SERIES IX.—PHARYNGOPNEUSTA.

ENTEROPNEUSTA. (*Balanoglossus.*)
TUNICATA. (Ascidians.) Pliocene—

SERIES X.—VERTEBRATA.

PISCES. (Fishes.)

LEPTOCARDII. (Pharyngobranchii) (*Amphioxus.*)
CYCLOSTOMI. (Marsipobranchii) (Lampreys, Hags, *Palæospondylus* (?)). Dev. (?)—

Selachii (Elasmobranchii.)
- **Pleuropterygii.** (*Cladodus*, &c.). Dev.—Perm.
- **Acanthodi.** (*Acanthodes*, &c.) Dev.—Perm.
- **Ichythotomi.** (*Pleuracanthus*, &c.) Carb.—Perm.
- PLAGIOSTOMI. (*Cestracion*, &c.) Carb.—
- HOLOCEPHALI. (*Ischyodus*, *Chimæra*, &c.) Dev.—

Placodermi.
- **Heterostraci.** (*Pteraspis.*) Sil.—Dev.
- **Aspidocephali.** (*Cephalaspis.*) Sil.—Dev.
- **Antiarcha.** (*Pterichthys.*) Dev.
- **Arthrodira.** (*Coccosteus.*) Dev.

Dipnoi.
- **Ctenodipterini.** (*Dipterus.*) Dev.—Perm.
- SIRENOIDEA. (*Ceratodus.*) Trias.—

Ganoidei.
- CROSSOPTERYGII. (*Holoptychius*, *Polypterus.*) Dev.—
- CHONDROSTEI. (*Sturgeons*, &c.) Trias.—
- **Heterocerci.** (*Palæoniscus*, &c.) Dev.—Jura.
- **Pycnodonti.** (*Pycnodus*, &c.) Jura.—Eocene.
- LEPIDOSTEI. (*Dapedius*, *Lepidosteus.*) Perm.—
- AMIOIDEI. (*Pachycormus*, *Amia.*) Jura.—

Teleostei.
- PHYSOSTOMI. Trias.—
- PHYSOCLYSTI. Cret.—

AMPHIBIA.

Labyrinthodontia. (Stegocephali) Labyrinthodonts.—Carb. —Trias.
CÆCILIA. (Apoda) (*Cæcilia.*)
URODELA. (Caudata) Newts and salamanders. Cret.—
ANOURA. (Ecaudata) frogs and toads. Eocene.—

REPTILIA.

Enaliosauria.
- **Ichthyosauria.** (*Ichthyosaurus.*) Trias.—Cret.
- **Plesiosauria.** (Sauropterygia), (*Plesiosaurus*, *Pliosaurus.*) Trias.—Cret.

CHELONIA. (Tortoises and turtles.) Trias.—

Theriomorpha.
- **Anomodontia.** (*Dicynodon*, &c.) Trias.
- **Placodontia.** (*Placodus.*) Trias.
- **Pariesauria.** (*Pariesaurus.*) Perm.—Trias.
- **Theriodontia.** (*Cynodracon.*) Perm.—Trias.

RHYNCHOCEPHALIA. (Hatteria, *Hyperodapedon.*) Perm.—
LACERTILIA. (Lizards.) Eocene—
Pythonomorpha. (*Mososaurus.*) Cret.
OPHIDIA. (Snakes.) Eocene—
CROCODILIA. (Crocodiles and alligators.) Trias.—

Dinosauria.
- **Sauropoda.** (*Atlantosaurus*, *Cetiosaurus.*) Jura.—Cret
- **Theropoda.** (*Megalosaurus.*) Trias.—Cret.
- **Orthopoda.** (*Stegosaurus*, *Iguanodon.*) Jura.—Cret.

Ornithosauria.
- **Pterosauria.** (*Rhamphorhynchus.*) Jura.—Cret.
- **Pteranodontia.** (*Pteranodon.*) Cret.

AVES (Birds).

Saururæ. (*Archæopteryx.*) Jura.
Ratitæ-Odontolcæ. (*Hesperornis.*) Cret.

AVES (Birds)—*continued.*

RATITÆ. (Ostriches, &c.) Miocene.—
Carinata Odontornæ. (*Ichthyornis.*) Cret.
CARINATA. (Common birds.) Eocene—

MAMMALIA (Mammals).

Allotheria. (Prototheria, Multituberculata), (*Microlestes*, &c.) Trias.—Tertiary.
MONOTREMATA. (*Echidna*, *Ornithorhynchus*). Pleistocene—
MARSUPIALIA. (Kangaroos, Opossums, &c.) Trias.—
EDENTATA. (Sloths and armadilloes.) Pliocene—

Cetacea.
- **Archæoceti.** (*Zeuglodon.*) Eocene.
- ODONTOCETI. (*Delphinus*, *Squalodon*, *Ziphius.*) Miocene.—
- MYSTICETI. (*Balæna.*) Miocene—

SIRENIA. (Dugong, *Halitherium.*) Eocene.—

Ungulata.
- **Condylarthra.** (Phenacodus.) Eocene.
- PERISSODACTYLA. (Horse, &c.) Eocene—
- ARTIODACTYLA. (Ox, deer, &c.) Eocene—
- **Litopterna.** (*Macrauchenia.*) Oligocene.—Pleistocene.
- **Amblypoda.** (*Coryphodon*, *Uintatherium*, &c.) Eocene.
- PROBOSCIDEA. (Elephants, &c.) Miocene—
- **Toxodontia.** (*Toxodon.*) Oligocene—Pleistocene.
- **Typotheria.** (*Typotherium.*) Oligocene.—Pleistocene.
- HYRACOIDEA. (Hyrax.)

Tillodontia. (Tillotherium.) Eocene.
RODENTIA. (Rodents.) Eocene—
INSECTIVORA. (Insectivores.) Eocene—
CHEIROPTERA. (Bats.) Eocene—

Carnivora.
- **Creodontia.** (*Hyænodon.*) Eocene.
- FISSIPEDIA. (Cats, dogs, &c.) Eocene—
- PINNIPEDIA. (Seals.) Miocene—

Primates.
- PROSIMIÆ. (Old apes, lemurs, &c.) Eocene—
- SIMIÆ. Apes and monkeys (*Dryopithecus*). Miocene—
- BIMANA. (Homo.) Pleistocene—

In preparing this table of the principal divisions (orders or sub-orders) of the animal kingdom, the classifications of Huxley, E. T. Newton, and Zittel have been chiefly followed. It will be seen by consulting it, that rather more than one-fifth of the known orders of animals are not found in a fossil state; nearly one-third of the orders are represented by extinct forms only, but this proportion would probably be very greatly increased if we knew anything of the soft-bodied animals of past geological times, and were better acquainted with the structure of those whose hard parts have been preserved. More than one-half of the groups have both fossil and living representatives.

In quoting the names of species of animals and plants in this work, the convenience of the student has been consulted in preference to any attempt being made to secure absolute accuracy or uniformity of procedure. In a few cases it has been found necessary to insert two names—that by which the fossil ought to be designated, and that which is familiar to most geologists. This course has been adopted in the case of the Ammonites, and of some large genera, the subdivision of which is inevitable. In all cases, however, the authors of the specific names are given.

INDEX

The names printed in italics are those of fossils and other objects illustrated by figures. Names of authors quoted are printed in capitals

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